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Technical Report

IGNITION OF THICK WOOD SPECIMENS BY HIGH-TEMPERATURE THERMAL RADIATION

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IGNITION OF THICK WOOD SPECIMENS BY HIGH-TEMPERATURE THERMAL RADIATION

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by

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ABSTRACT

An investigation was undertaken to determine the probability of ignition of thick woods by thermal radiation. A carbon-arc source was used to simulate the thermal radiation from a nuclear weapon.

Measurements were made to determine the irradiance and time necessary to produce glow and flaming ignition in ponderosa pine, Douglas fir, and maple. The results of this study are presented in the form of graphs of irradiance as a function of time for several moisture contents for each type of wood. In all cases on the graphs, the locations of the areas of char, persistent glowing ignition, and persistent flaming ignition are shown. The values of Q, total thermal energy necessary to produce sustained burning (with or without flame), can be easily computed from these data. They range from a minimum value of about 19 cal/cm^2 for very dry pine to several thousand calories/cm^2 for wood with a very high moisture content. It was concluded that for sound solid woods of a normal moisture content, it is almost impossible to start continued ignition with nuclear weapons of a size less than about 100 Mt at a distance where blast damage would not be severe. An appendix describes the high-intensity thermal-radiation facility used to conduct the investigation.

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INTRODUCTION

It is known from previous studies[1,2,3,4] that fires can result from the thermal radiation given off by a nuclear-weapon explosion at a distance where the blast damage is not extreme. These fires are generally started in fine kindling fuels, such as paper or rotted punky wood. Other investigators have done experimental work on incendiary effects with wood cribs and on the spread of fires in beds of pine needles.[5,6] Also, much experimental work has been done and is still being done on the ignition characteristics of thin films of alpha cellulose by Butler, Martin, Broido, and others.[7]

Little work has been done, however, on the ignition of thick wood specimens by thermal radiation from nuclear weapons. Outside the 2-psi blast-wave level, almost without exception, the fires that are started in solid wood are of only a transient nature. This is because the body of the wood is not heated to a high enough temperature[8] to allow the fire or glowing ignition to continue after the removal of the external heat source. There exists the possibility that fires may be started and sustained in cracks in such wood. In general, however, this has not proved to be the case.[9,10] An explanation may be that the thermal conductivity of wood surrounding such cracks is great enough to prevent the wood from rising to a temperature[11] where combustion will be sustained.

Very large nuclear weapons of one hundred to a thousand megatons and larger, could be detonated at a height where no appreciable blast damage[12] would be caused. Rogers[13], and Miller and Passell[14] at Stanford Research Institute have calculated the level of thermal radiation reaching the ground from these very large weapons. Our experiments show that glow or flaming ignition could be initiated by such values of irradiance.

Fires can be started in solid timbers which are exposed to low levels of irradiance for long periods such as would exist in large fires or in fire storms or conflagrations such as occurred at Hamburg, Hiroshima, and the fires at Ottawa and Hull[15] in Canada. The complete consumption of all combustible material in such fires indicates that sound heavy timbers will burn to destruction if they are raised to a high enough temperature throughout their entire volume.

EXPERIMENTAL PROCEDURE

The woods that were tested were ponderosa pine, Douglas fir, and maple. The wood samples were 3/8 of an inch in diameter and 1/2 inch long, with the growth rings parallel to the front surface of the sample. Normal kiln-dried wood was procured for test material, and it has a moisture content of about 8 to 10%.

The percentage moisture content was calculated by a method devised by the U. S. Forest Products Laboratory. This method is described in the Wood Handbook.[16] The sample was weighed after it had been taken out of the conditioning chamber. Then it was placed in an oven which operated at a temperature of between 214 and 221°F until its weight (dry) reached a constant value. The percentage of moisture content is described as

$$\frac{\text{sample weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100$$

Some samples of ponderosa pine were tested to determine their glow-ignition limits after they had been dried in the oven according to the U. S. Forest Service procedure described above. These oven-dried samples gave unreliable results. Therefore, it was decided to remove the water from the wood samples by placing them in a dessiccator over phosphorus pentoxide (P_2O_5). With these samples, reliable test results were obtained. It was found that these samples had 3% moisture content when tested by the Forest Service oven drying test. This 3% was probably not water, but volatile constituents of the wood. After this, all "dry" samples for testing for glow ignition were dried over phosphorus pentoxide or Dehydrite* to reduce their moisture content to a minimum without affecting their volatile constituents. Other samples were prepared by placing them in the environmental test chamber of the laboratory, which has a relative humidity of 100% and a temperature of 70°F. After varying lengths of time, the samples were removed and their moisture content was determined. The percentage moisture content was calculated as described above after the sample had been dried in an oven at a temperature between 214 and 221°F.

PROCEDURE FOR EXPOSING THE TEST SAMPLES TO THERMAL RADIATION

A wood sample, either ponderosa pine, Douglas fir, or maple that had the moisture content that was to be tested was selected. The wood samples of a desired moisture content were stored in rubber-stoppered jars until needed. First a value of irradiance was selected for a particular experiment. A combination of the wire screens** was selected to give the desired value of irradiance for the experiment. A water-cooled radiometer was placed in the sample position to measure the value of irradiance. It was removed and the test sample put in the same place. A time for exposure was selected, and the sample was exposed. The result of the experiment was recorded, as well as the kind of wood, the moisture content, the irradiance value, and the exposure time.

* Available as a dehydrating agent from A. H. Thomas & Co., Philadelphia; similar in its properties to phosphorus pentoxide.

** See the Appendix for a description of the exposure device.

To determine an experimental point, at least three (and in some cases as many as 14) identical exposures were made. In cases where several exposures were made, the result recorded was that which happened to the largest percentage of the samples tested. This procedure was followed using increasing times of exposure until 40 seconds was reached. A different value of irradiance was then selected by changing the screens, and the same procedure was repeated. This method was repeated until all the necessary data were obtained to show the thermal response of the wood chosen.

The boundaries of the regions where glow and flaming ignition occurred received special attention. Many points were obtained in these regions that are not shown on the graphs because of crowding. The glow- and flaming-ignition limits were determined if they were within the capacity of the apparatus.

Glow ignition was originally defined as any glow in the solid wood that lasted for more than 5 seconds. Understandably, with longer exposures, the glowing of samples persisted over longer periods. In fact, some samples glowed for over 60 seconds, which resulted in the complete destruction of the sample.

Graphs for the various woods, with the irradiance as the ordinate and time as the abscissa, are given for several values of moisture content for each wood. Early in the investigation, when ponderosa pine was being tested, the time that glow ignition persisted was not always recorded. If the sample glowed for 5 seconds or more, it was reported as glow ignition. Later, when Douglas fir and maple were used as samples, the time for glow ignition was recorded and was shown by appropriate symbols on the graphs.

Due to variations of the arc, the values of irradiance generally have an accuracy of about ±4%. Under bad operating conditions it may be not worse than ±5%. This uncertainty is caused by the variation of the radiant emissive power of the arc. This power varies from time to time due to the motion of the positive carbon in the lamp mechanism during the automatic-feeding process. There are also small nonsystematic errors in the timing, which should not exceed 1%. Thus, the overall accuracy of the exposures are conservatively estimated to be about ±5%.

Some of the exposures on ponderosa pine were repeated after a period of about one year, and the values were found to correspond to the values found originally within the stated experimental error.

Originally, a class of ignition phenomena described as ash ignition was used. Since this phenomenon is short-lived (5 to 15 seconds), and the mass of material involved is very small, the probability of any fire being caused by it is very slight. All samples that "ash-ignited" are now reported as "char."

INVESTIGATION OF VARIOUS WOODS

Ponderosa Pine

Ponderosa pine was the first wood to be investigated, and the limits of glow ignition were determined for several moisture contents. These are shown in Figures 1 through 5. In addition to the glow-ignition limits, the limits for flaming ignition are

also included on these graphs. In all cases where glow ignition or flaming ignition occurs, the body of the wood had to be raised to a temperature high enough for combustion to be sustained. This temperature is in the neighborhood of 600° C.[17] The points of glow ignition have been plotted to indicate the time during which the glow persisted. As greater amounts of energy are delivered to the sample, the glow ignition persists for a longer time, and finally, if the amount of energy delivered is sufficient, the sample will spontaneously ignite and remain burning until it is completely destroyed.

Table I lists the samples of ponderosa pine that were tested and their moisture contents. Also given is the number of the figure showing ignition behavior of each sample. A 3% moisture content would correspond to wood that has been exposed a long time in a desert environment. Glow ignition or flaming ignition can be initiated in these samples with the lowest energy (about 20 cal cm^{-2}) of any of the wood samples that were tested.

Table I. Ponderosa Pine

Sample	Moisture Content (%)	Figure No.
Dried over P_2O_5	3.0	1
Kiln dried	9.6	2
75% RH room	12.3	3
95% RH room	75	4
100% RH room	100	5

Figure 1 shows the response of ponderosa pine dried over phosphorus pentoxide until the wood had a moisture content of 3%. A curve was drawn between the points corresponding to the wood that was not ignited and the wood that was ignited by the thermal-radiation exposure. For short exposure times, there was no glow ignition; either the wood caught fire or simply charred. For the longer exposure times and low irradiance values, glow ignition did occur.

Figure 2 shows the response of kiln-dried ponderosa pine as received from the supplier. It had a moisture content of 9.6%. The curve shows areas where char, glow ignition, and flaming ignition occurred. At some values of irradiance (i.e., 10 cal/cm^2/sec) the wood first chars, then glow-ignites, and then, with longer exposure times, it bursts into flaming ignition. The lines separating char, glow ignition, and flaming ignition are approximately straight on the log-log plot. In several instances, when the wood sample was exposed to a very high level of irradiance it received enough energy in a short time to cause a short transient ignition during exposure, but the ignition did not continue after the exposure was terminated. The reason for this is that sufficient heat could not be conducted into the body of the wood sample to raise it to a temperature where persistent ignition could occur. The wood at the surface was simply ablated.

Figure 3 shows the response of ponderosa pine with a moisture content of 12.3%. At this moisture content, glow ignition and char were the principal responses. There are three points for flaming ignition. If higher irradiances had been tried at around 20 or 30 seconds, the curve would be extended upward similar to the curve in Figure 2 for the kiln-dried lumber.

Figure 4 is the response of ponderosa pine with a moisture content of 75%. This wood exhibited no flaming ignition, only glow ignition and char.

Figure 5 is the response of ponderosa pine with a moisture content of 100%. It shows the same effect as Figure 4, only to a greater degree.

Douglas Fir

The Douglas fir samples that were tested are shown in Table II.

Table II. Douglas Fir

Sample	Moisture Content (%)	Figure No.
Dried over Dehydrite	0.8	6
Kiln-dried	9.2	7
100% RH room	16.0	8
100% RH room	23.2	9
100% RH room	101.0	10

Figure 6 shows the response to thermal radiation of Douglas fir samples dried in a desiccator over Dehydrite. They had a moisture content of 0.8%. Upon thermal exposure, the samples either became charred or burst into flame which continued for 5 to 75 seconds. In the latter case, practically nothing of the sample remained. In general, the exposure time for the sample to become ignited decreased with an increase in the irradiance. At very low irradiance levels the samples merely charred, even after an exposure as long as 40 seconds. In no case was glow ignition observed.

Figure 7 is for kiln-dried Douglas fir. This had a moisture content of 9.2%. As in the case of the samples that were dehydrated, there were no instances of glow ignition. The wood either charred or burst into flame. The lines separating the samples that charred and the samples that burst into flame are similar to the curve in Figure 2 for the glow ignition of ponderosa pine. These curves cannot be compared quantitatively, because they are for a different reaction. One is glow ignition and the other is flaming ignition.

Figure 8 shows the response to thermal radiation of the Douglas fir samples with a 16% moisture content. This set of samples showed examples of char, glow ignition, and flaming ignition. It is difficult to draw any curve through these points. However, there is generally a tendency for more damage to occur at the higher levels of irradiance.

Figure 9 shows the thermal response of Douglas fir with 23.2% moisture content. These samples were either charred or glow-ignited. There were no examples of flaming ignition.

Figure 10 shows the response of Douglas fir with 101% moisture content. The samples in this experiment either charred or glow-ignited. There were no examples of flaming ignition in this experiment.

Maple

Maple samples were prepared in exactly the same manner as the two other woods tested. Table III shows the various maple samples tested along with the number of the figure showing their response to exposures to thermal radiation.

Table III. Maple

Sample	Moisture Content (%)	Figure No.
Dried over Dehydrite	2.7	11
Kiln-Dried	9.2	12
100% RH room	17.2	13
100% RH room	25.2	14
100% RH room	43.6	15

The kiln-dried maple as received from the lumber yard had a moisture content of approximately 9.2%. Compared with the other wood samples, the maple samples presented difficulties in either drying them out or increasing their moisture content. Specimens of maple were placed in a desiccator over Dehydrite for approximately two months, and the moisture content could be reduced only to 2.7%. The samples placed in the 100% RH chamber had a moisture content of only 43.6% after 24 days of exposure in this chamber.

The responses of the kiln-dried samples (moisture content 9.2%) of maple to thermal radiation, in general, are qualitatively similar to those of ponderosa pine. The behavior of the maple samples dried over Dehydrite (2.7% moisture content) differed markedly from that of the 3% moisture content samples of ponderosa pine. In general, it took about four times the amount of energy to produce in the maple the same effect that occurred in the ponderosa pine. In the kiln-dried maple samples, the same effects were produced at approximately twice the energy delivered to the ponderosa pine samples. The curves for maple show a good delineation between glow ignition, char, and flaming ignition. For the kiln-dried maple, there is a large region in which glow ignition can occur. With increasing moisture content, the flaming ignition area decreases to practically the vanishing point at the highest moisture content.

EXPERIMENTS CONDUCTED TO SIMULATE THE EFFECTS OF CRACKS AND CREVICES

Previous work[18,19] suggested that fires could be started more easily by thermal radiation from a nuclear weapon in cracks or holes in solid wood. Since no source of parallel radiation of sufficient intensity to simulate the thermal radiation from a nuclear weapon was available, a method was devised to obtain light which was less convergent than that used in the first series of experiments. Samples with and without holes were exposed to a beam of smaller convergence to determine whether or not any difference existed in their response to thermal-radiation exposures.

An aperture 30 inches in diameter was cut in an aluminum screen. This was placed in the parallel beam between the mirrors, cutting down the convergence of the beam from a 120-degree angle to approximately 90 degrees. Samples of ponderosa pine were prepared with a 90-degree hole countersunk in the center of the plane surface facing the beam. A sample holder was placed so that the axis of the 90-degree converging radiation was perpendicular to the surface of the sample. A series of samples with and without holes were run at various irradiances. No great differences were noted in the time required for irradiance to start glow ignition. In all instances where glow ignition occurred, it was on the front edges of the sample and not in the hole.

From these preliminary experiments, it has been concluded that cracks or crevices in solid wood samples probably will not greatly influence the ignitability of wood from thermal energy received from a nuclear detonation. When plane parallel radiation is incident on a sample which has a crack or crevice in it, the radiation may penetrate the crack or crevice and be absorbed there, as well as in the wood on the front surface of the sample. However, the large mass of wood surrounding the crack or crevice will rapidly conduct away any heat absorbed in the crack or crevice. Therefore, the wood around the crack in the sample will not reach the temperature necessary for sustained glowing or flaming ignition any more quickly or easily than simple plane solid wood. Actual field tests[18] of samples with grooves and holes showed less damage in grooves with the smallest included angles, confirming our findings.

COMPARISON WITH OTHER WORK ON CELLULOSIC MATERIALS

Plots of the normalized radiant exposure (Q/PCL) as a function of the normalized irradiance (HL/K), are shown in Figures 16, 17, and 18. The dimensions and names of the quantities involved are tabulated below. These results were computed from the raw data by computer. The computer print-out is available on special request from the U. S. Naval Civil Engineering Laboratory Technical Library.

Q = Exposure in cal cm^{-2}	P = Density in gm cm^{-3}
C = Specific heat in cal gm^{-1} $(°C)^{-1}$	L = Thickness in cm
H = Irradiance in cal cm^{-2} sec^{-1}	K = Thermal conductivity cal sec^{-1} cm^{-2} $(°C^{-1} cm)$

In general, for glow or flaming ignition, larger values of the normalized radiant exposure (NRE) and normalized irradiance (NI) are required than for materials that simply char. The regions of flaming ignition, glow ignition, and char on these graphs are well defined, and in general the curves separating the regions have a positive slope. The values of these two parameters, NRE and NI, are greater than those reported by Martin[20] for his experiments with the alpha cellulose. This is to be expected, for the samples used in our experiments were over an order of magnitude thicker than the samples used in Martin's experiments. If one extrapolates Martin's ignition-behavior curves, they enter into the region where our data for char (or ignition) and glow or flaming ignition (persistent ignition) are plotted.

CORRELATION OF SQUARE-WAVE EXPOSURES WITH WEAPON EXPOSURES

Since all our data are for square-wave exposures, these values should be converted to the exposures expected from nuclear weapons. There is no simple method for doing this exactly; however, the following method has been suggested as a useful approximation.

To convert the square-wave exposures to equivalent weapon exposures for approximately the equal effect, one uses the following relations:[21]

$$t_s = 4t_m \tag{1}$$

$$H_s = 0.6\, H_m \tag{2}$$

$$W = t_m^{\,2} \tag{3}$$

$$Q = H_s t_s \tag{4}$$

where t_s = time of square-wave exposure (sec)

t_m = time of second maximum of weapon (sec)

H_s = irradiance of square wave (cal cm^{-2} sec^{-1})

H_m = irradiance of second maximum equivalent weapon pulse (cal cm^{-2} sec^{-1})

W = the yield of weapon (megatons)

Q = the thermal energy (cal cm^{-2})

From the time of the square wave, t_s, one can calculate the equivalent weapon yield, W:

$$W = \frac{t_s^{\,2}}{16} \tag{5}$$

From the equivalent weapon yield and the thermal energy, Q, received, one can calculate the distance, D, in miles by means of figure 7.105 (Glasstone[22]). Knowing D and W, one can calculate the overpressure, P, in pounds per square inch at the distance, D, by use of the equation and graph in Glasstone.[23]

In order to make practical use of these data, one has to convert the experimental values of time and irradiance into the values of weapon yield, the distance from the weapon, and the values of thermal energy and peak overpressure that can be expected there. Figures 1 through 16 give the experimentally determined values of t_s and H_s for the regions where threshold glow ignition can be expected.

In order to make these conversions, Equations 1 through 5 must be used, as well as the figures and equations mentioned in References 22 and 23. However, the Nuclear Bomb Effects Computer, attached to the back cover of Glasstone's 1964 edition, is more convenient to use for these computations. For bombs of a yield greater than 20 megatons, it is necessary to extrapolate to find the distance. This can be done by plotting the previously computed data (see Figure 19). The values of overpressure for yields greater than 20 megatons may be computed by the Bomb Damage Computer prepared by the Rand Corporation, Santa Monica, California.

As an example, the values for the threshold of glow ignition (Figure 2) for kiln-dried ponderosa pine have been calculated for several of the points on the graph. The resulting weapon yields, distances, pressures, and thermal energy received are shown in Table IV.

Table IV. Threshold Glow Ignition of Kiln-Dried Ponderosa Pine

t_s	t_m	H_s	Q	W	D	P
40	10	1.5	60	100	32	2.2
30	7.5	1.8	54	56	24	2.5
20	5	4.0	80	25	15	4
16	4	5.5	88	16	11	5
9.5	2.4	10	95	6	6.4	7

All the other data can be reduced in a similar manner for the various effects measured and the weapon size and distance found to produce this effect.

Admittedly, the equations used to relate square-wave pulses to equivalent weapons are probably accurate only to within a factor of two. Nevertheless, it can be reasonably concluded that weapons corresponding to the square-wave pulses producing sustained ignition in the woods studied would produce significant blast damage if the weapon yield was less than 100 megatons.

FINDINGS AND CONCLUSIONS

1. At distances where blast damage to wooden structures is not severe, it is highly improbable that sound solid wood will be ignited by the thermal radiation from nuclear weapons with a yield of less than 100 megatons. Therefore, it appears that there is no need to continue experiments with thick wood samples using high-temperature high-intensity thermal radiation.

2. Wood which has a high moisture content or a high density is more difficult to ignite than dry wood or wood with a low density.

3. When Douglas fir was dry, the wood either charred or flame-ignited; it only glow-ignited if the moisture was greater than 20%. Glow ignition occurred even in the driest samples of both ponderosa pine and maple (about 3% moisture content).

4. Holes or cracks appear to have no appreciable effect on the glow-ignition limits of sound wood.

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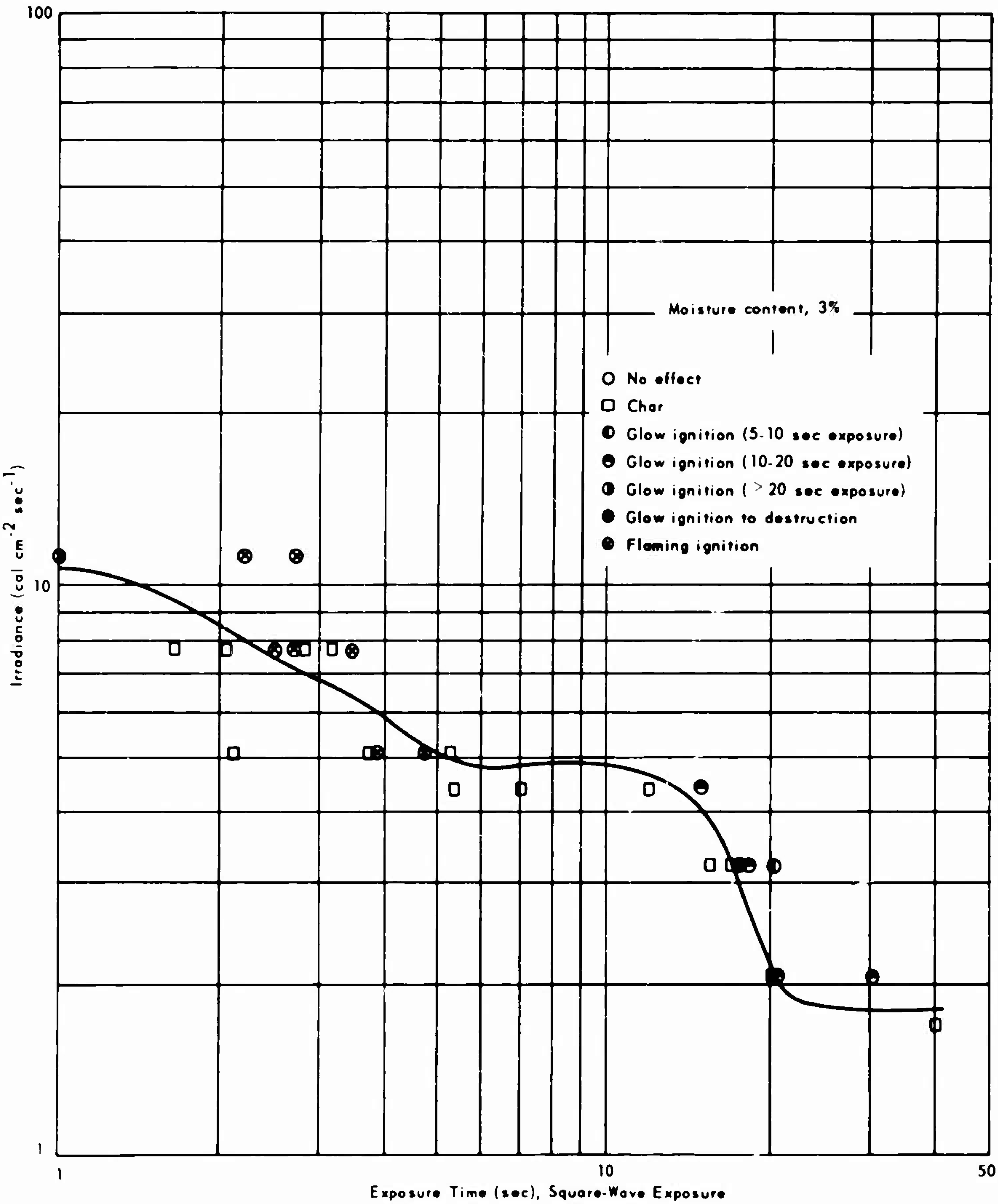

Figure 1. Response of ponderosa pine (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

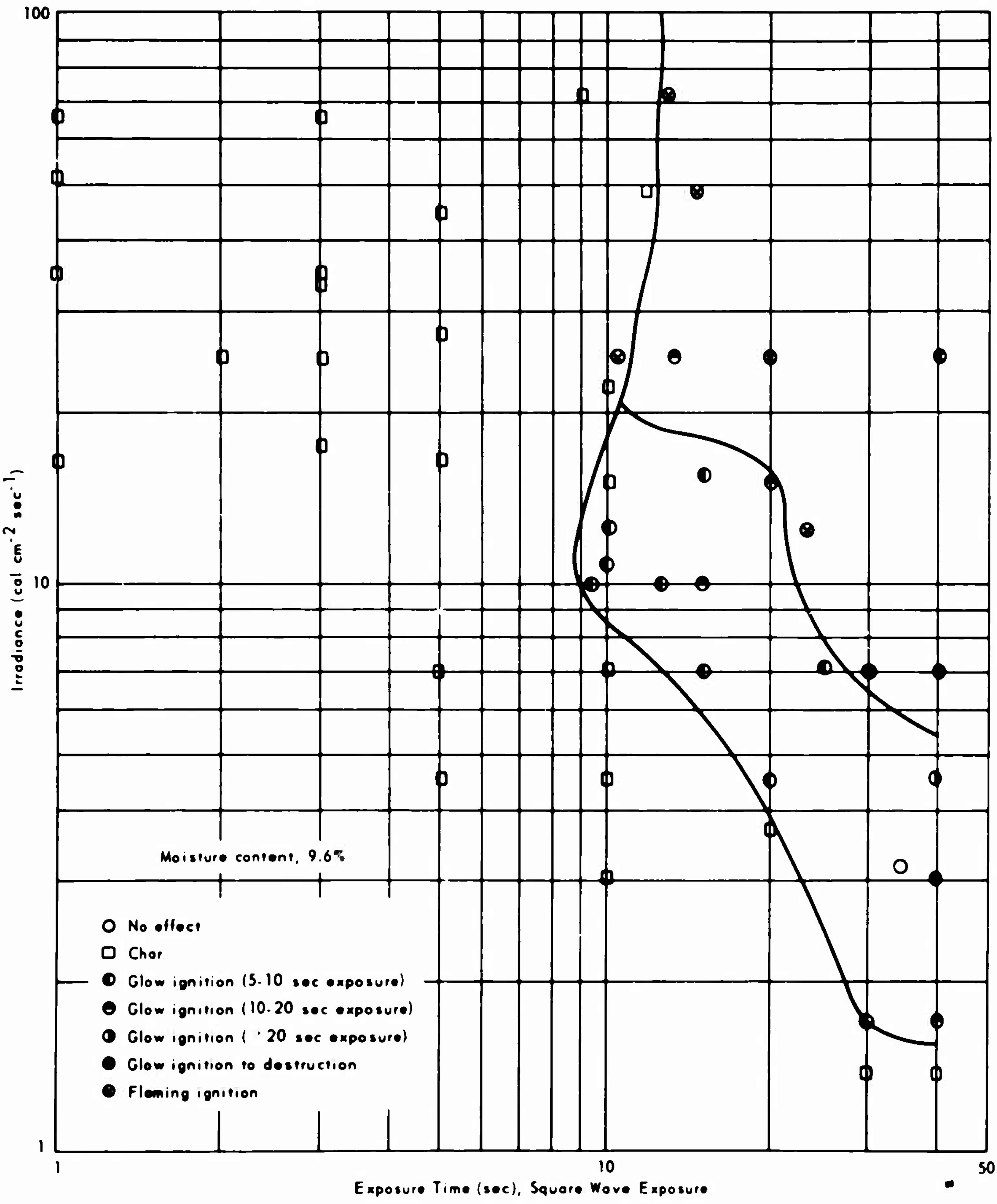

Figure 2. Response of ponderosa pine (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

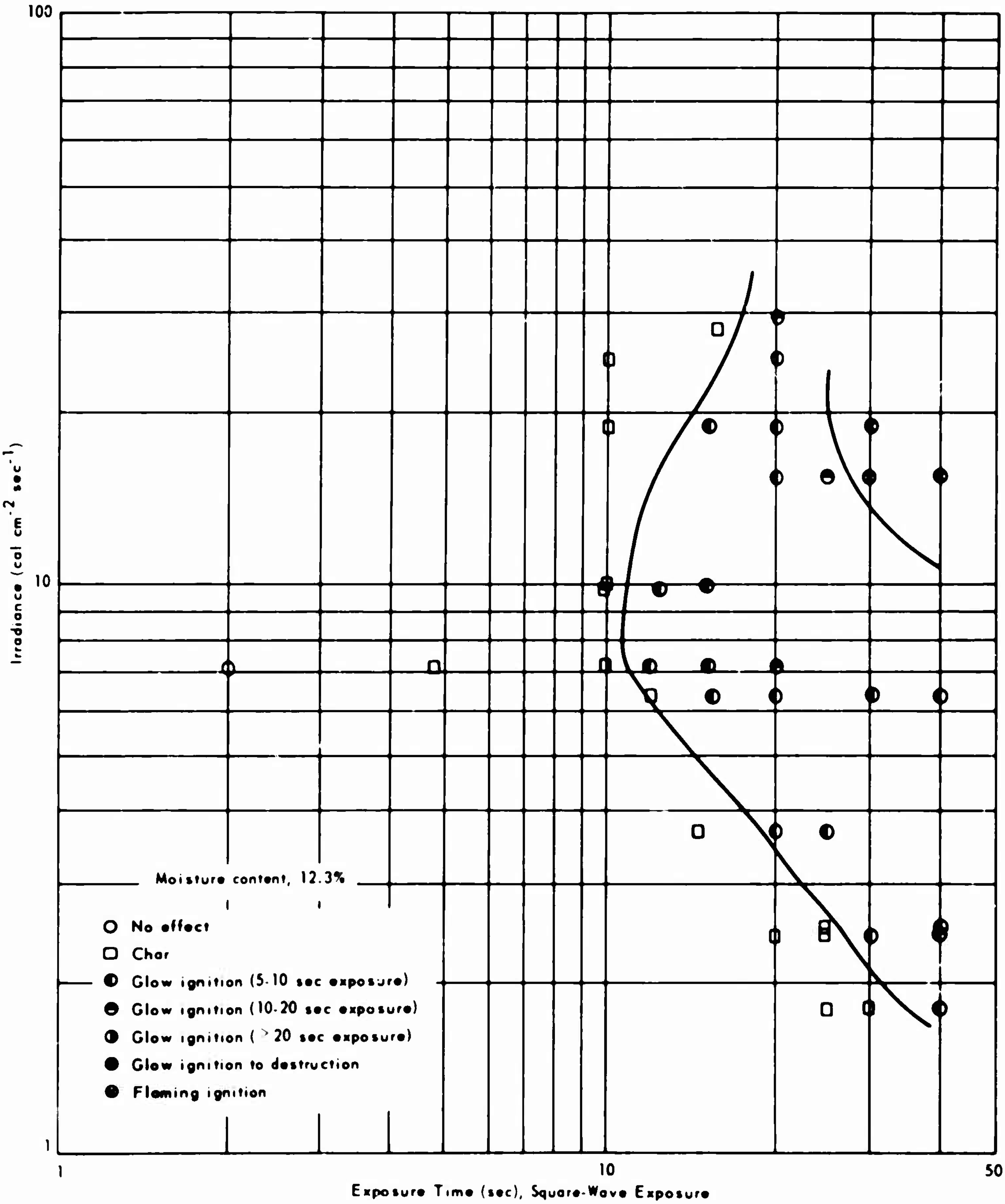

Figure 3. Response of ponderosa pine (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

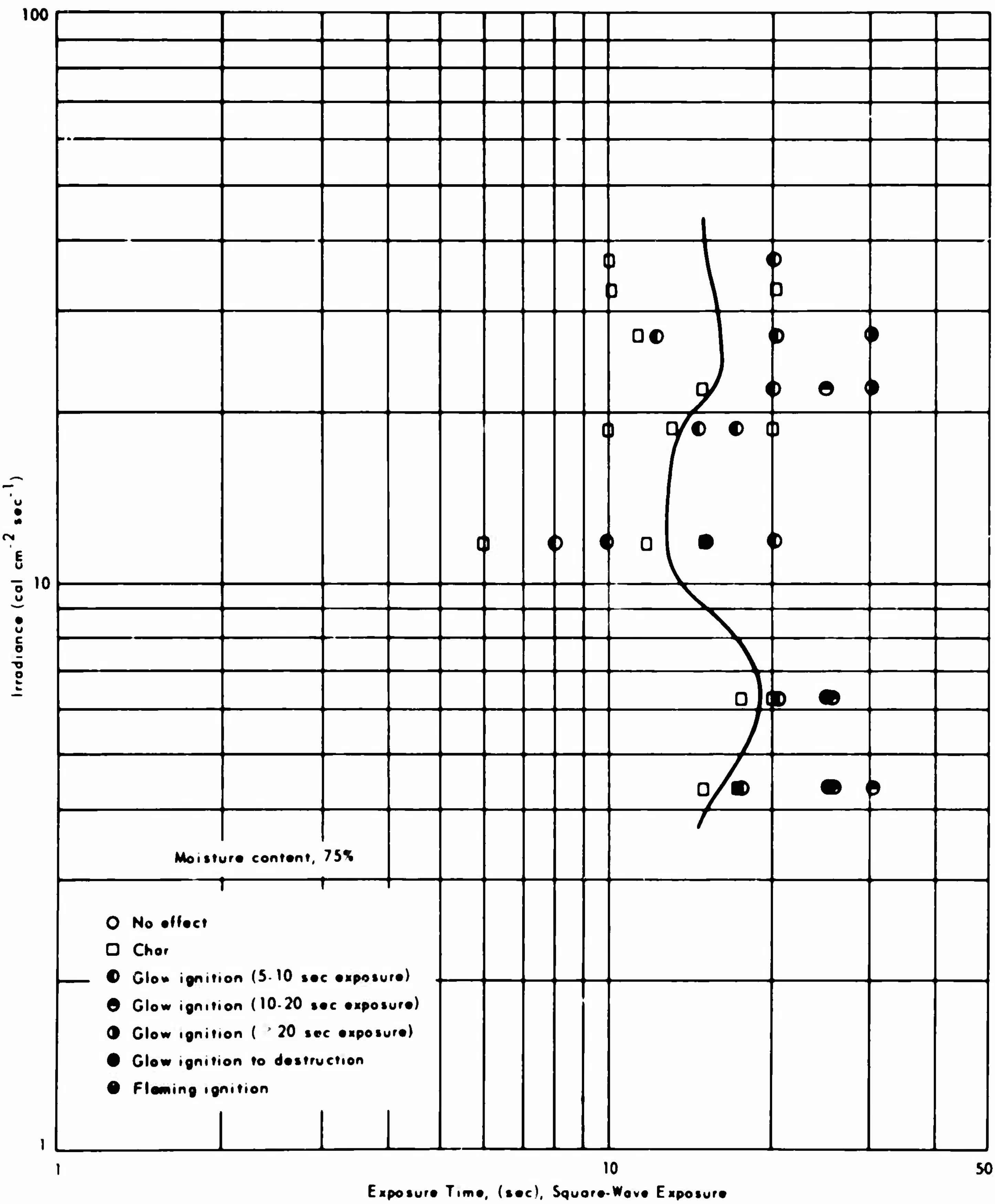

Figure 4. Response of ponderosa pine (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

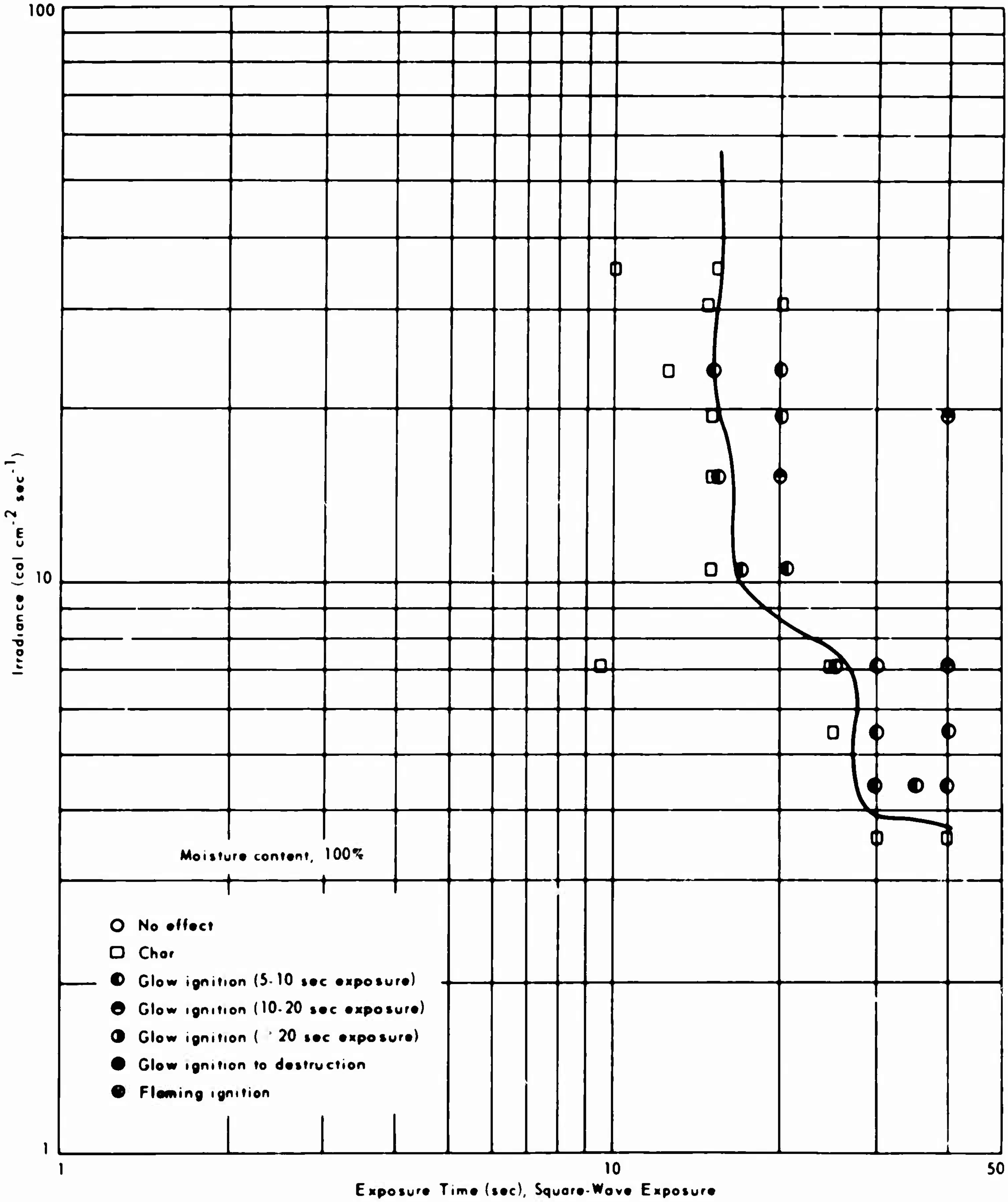

Figure 5. Response of ponderosa pine (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

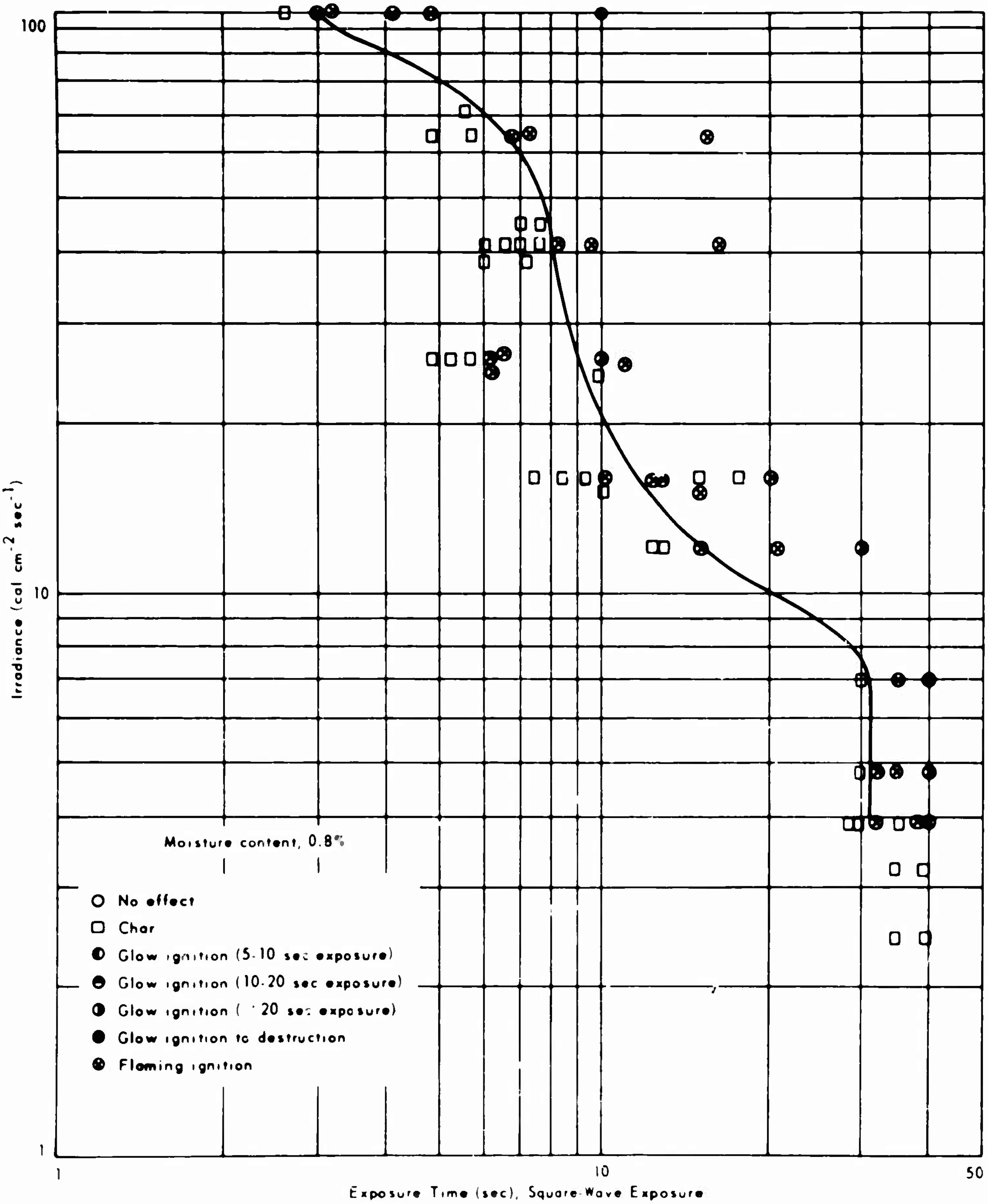

Figure 6. Response of Douglas fir (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

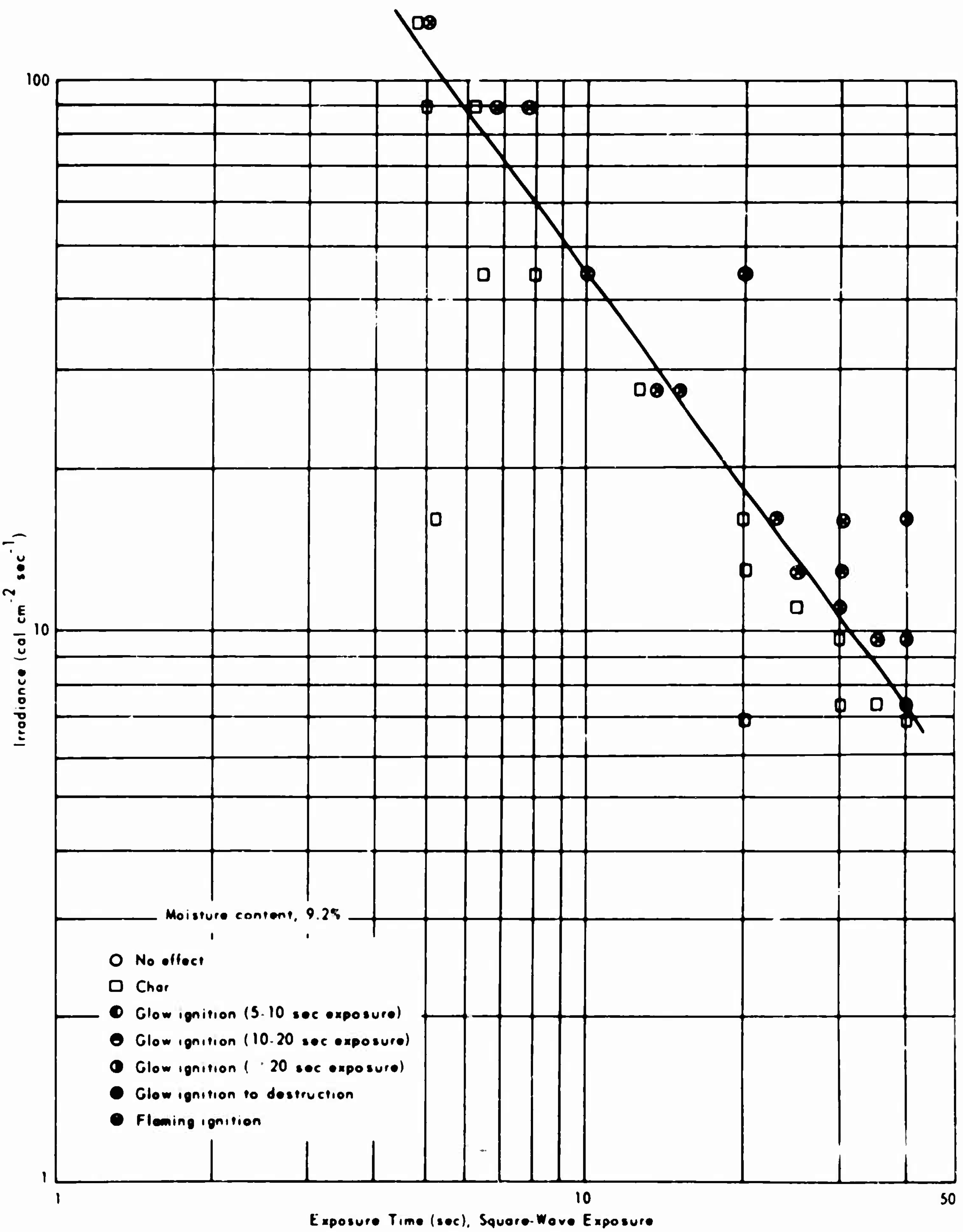

Figure 7. Response of Douglas fir (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

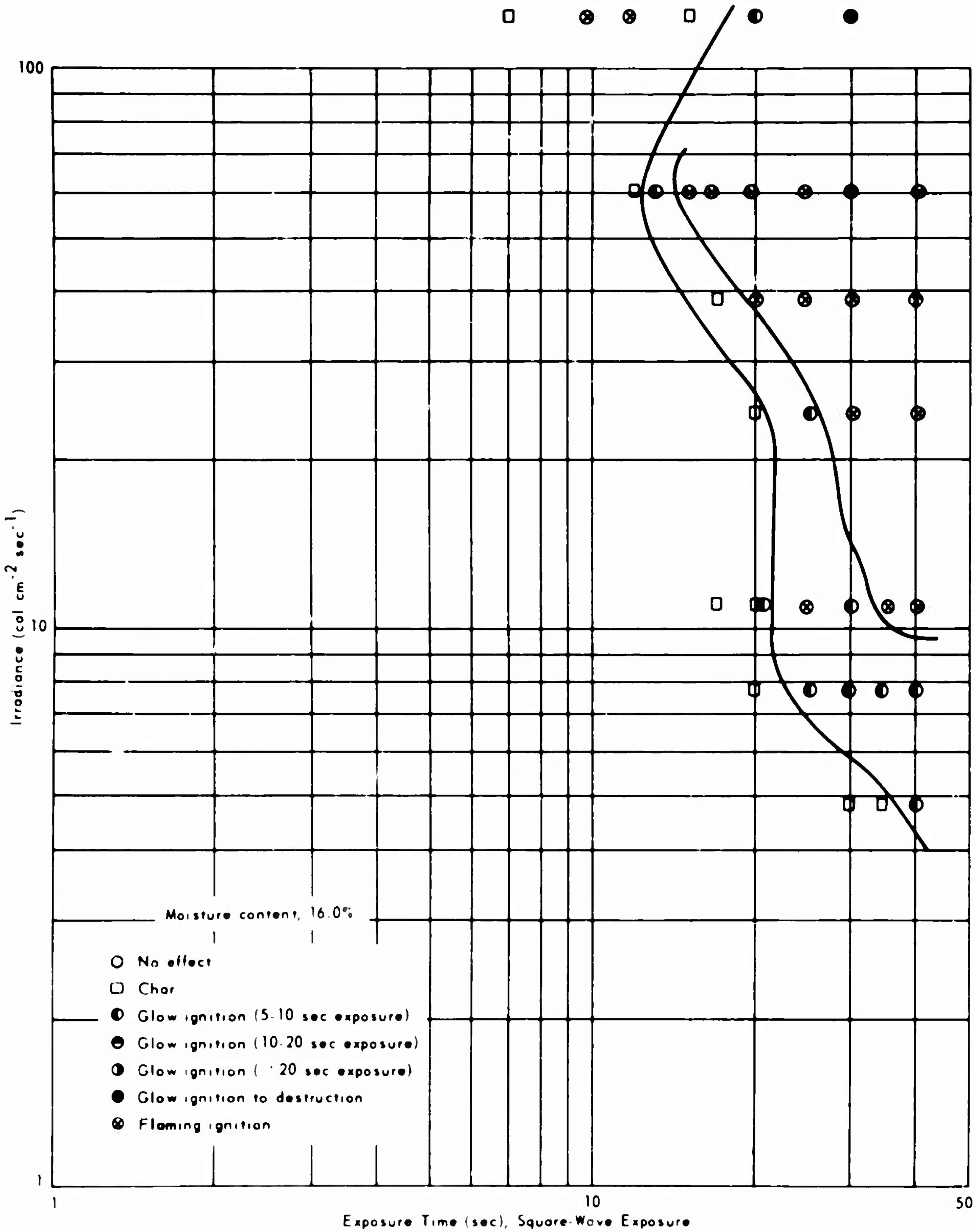

Figure 8. Response of Douglas fir (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

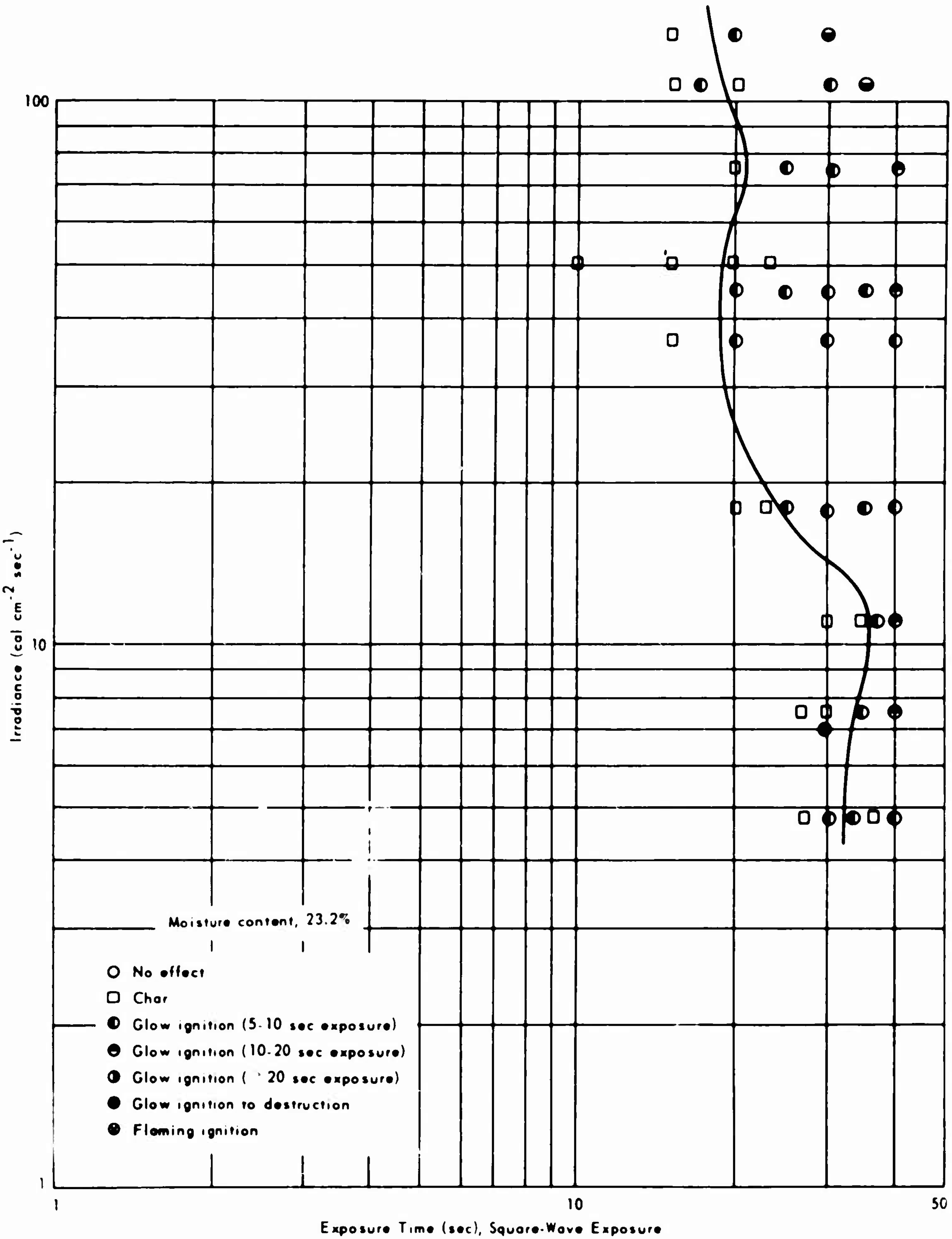

Figure 9. Response of Douglas fir (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

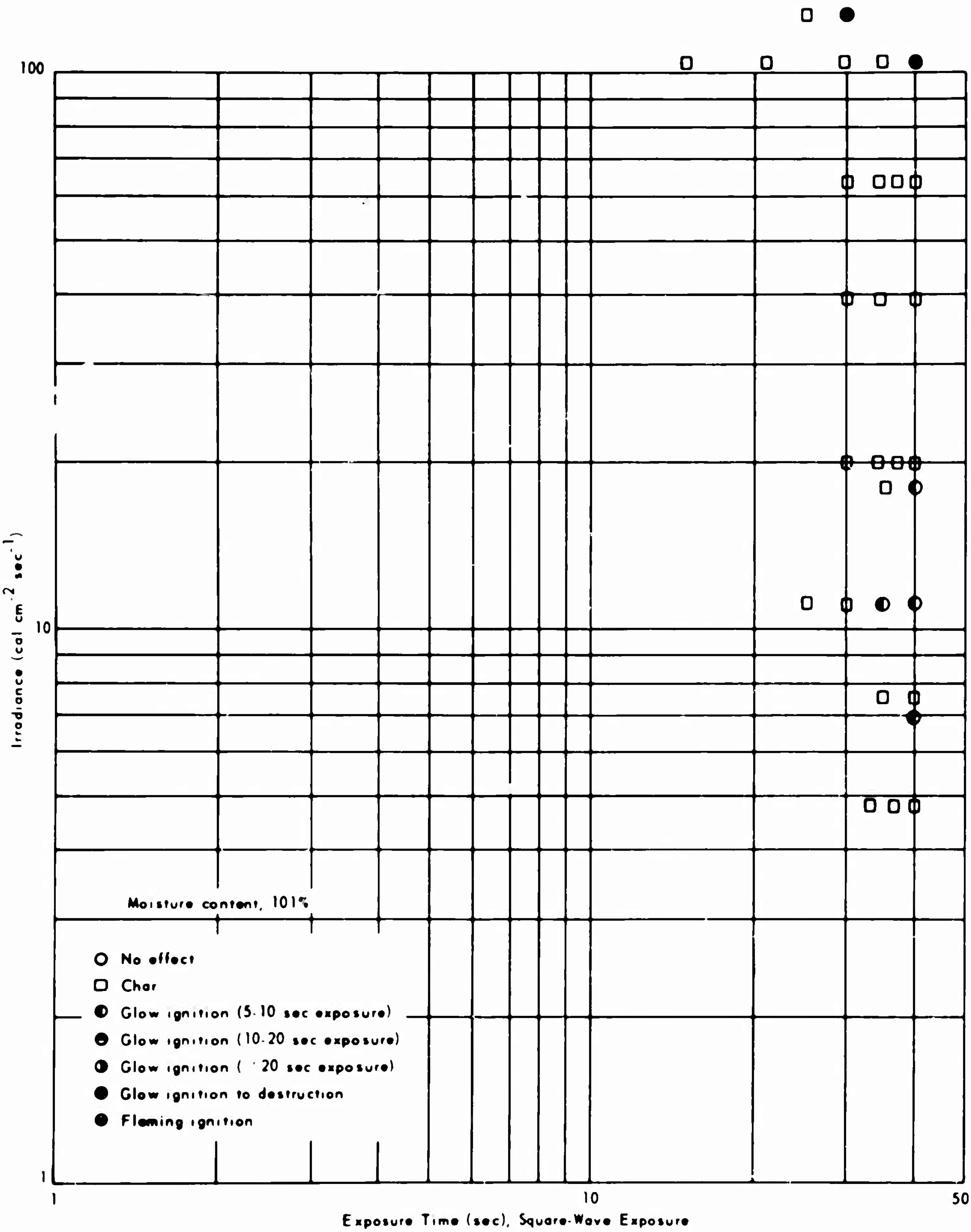

Figure 10. Response of Douglas fir (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

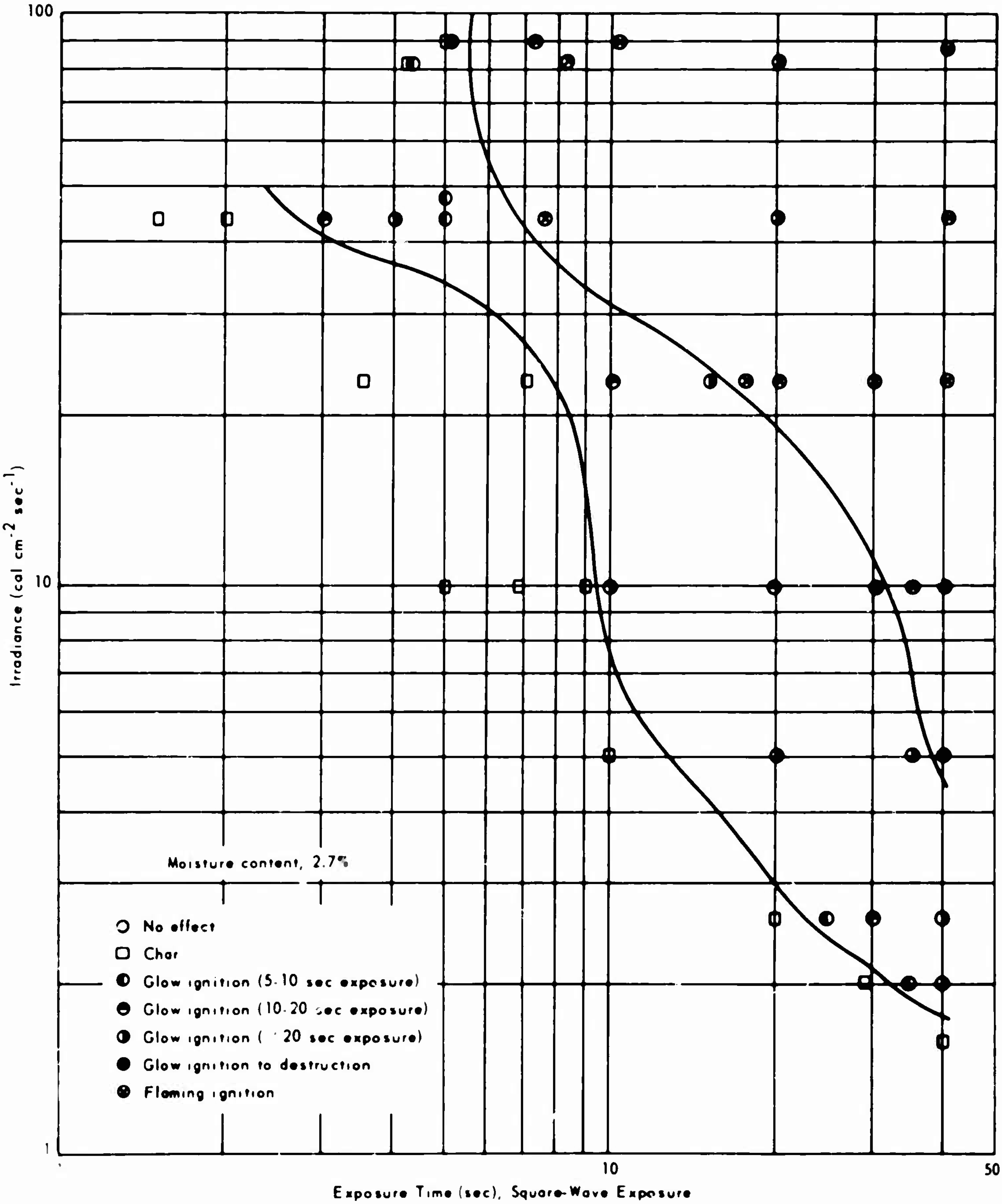

Figure 11. Response of maple (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

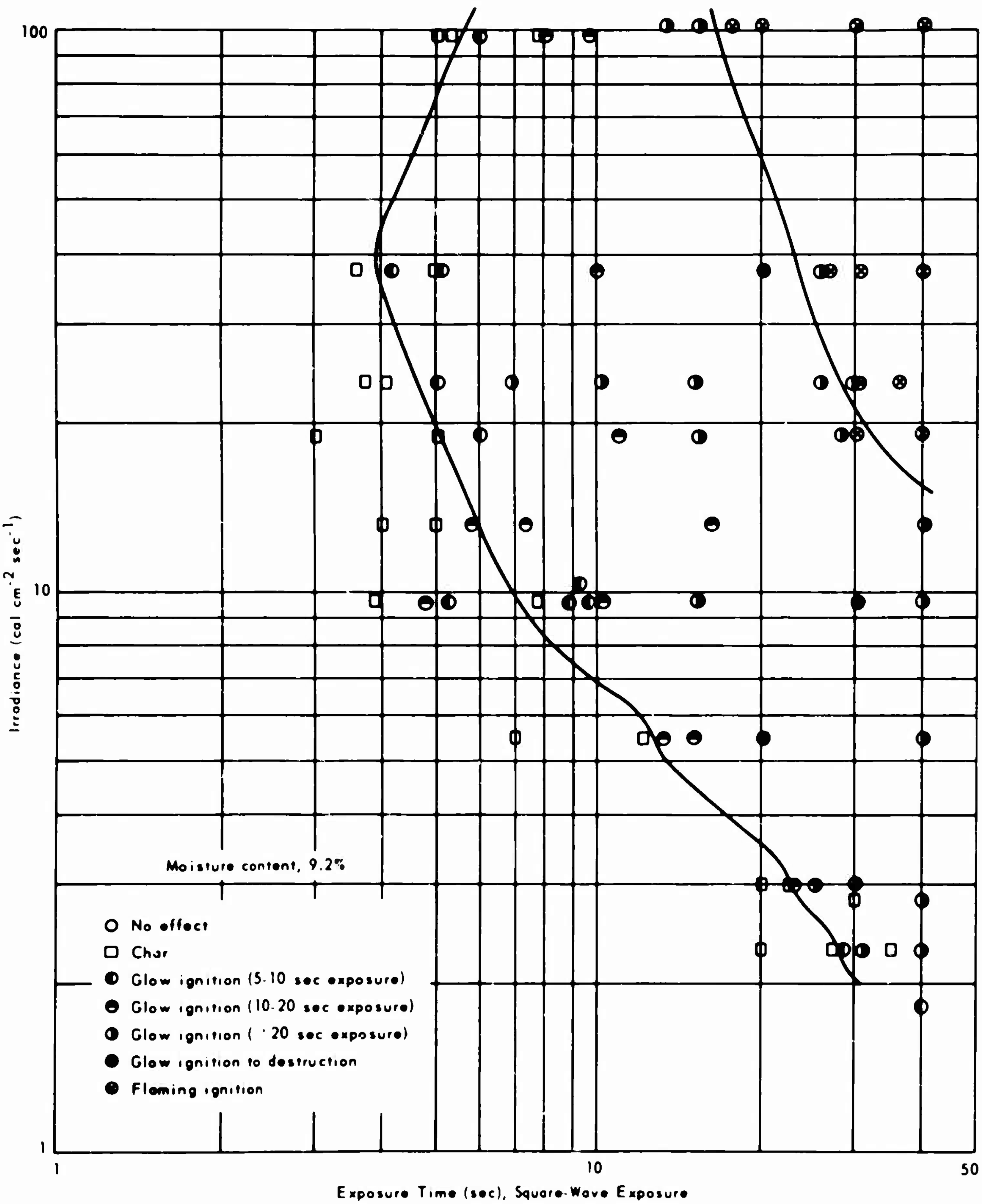

Figure 12. Response of maple (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

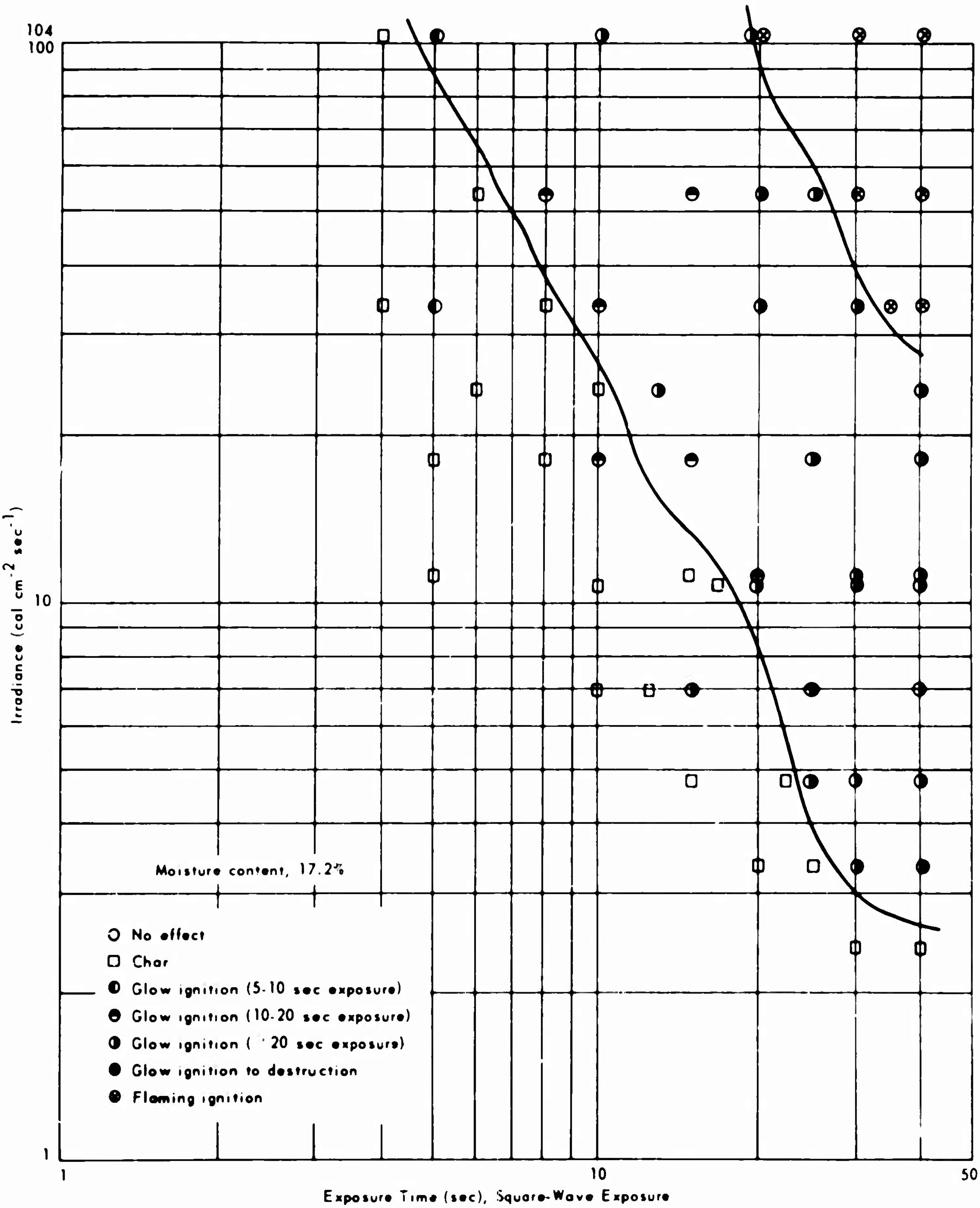

Figure 13. Response of maple (3/8 x 1/2-inch) cylinders to exposure of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

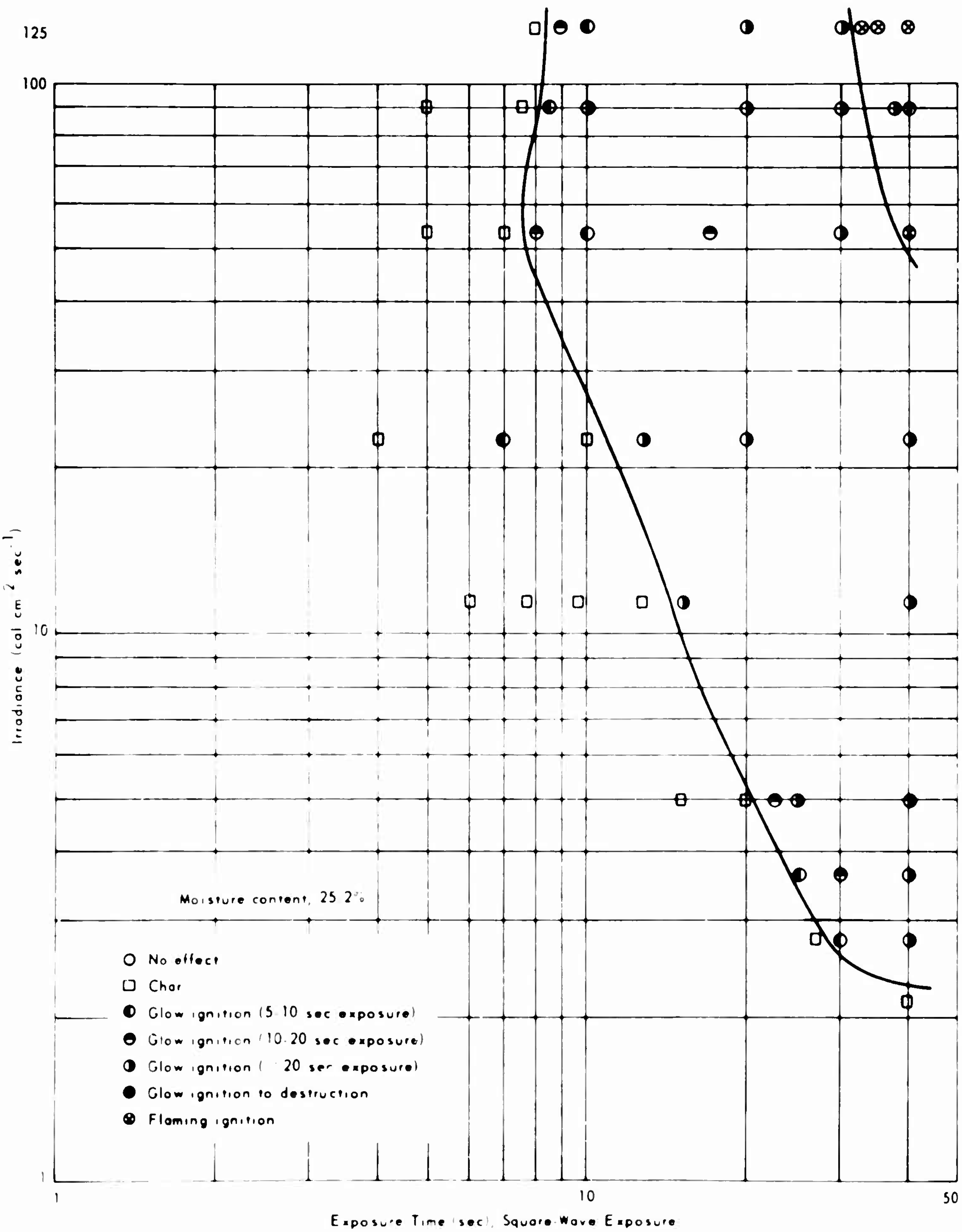

Figure 14. Response of maple (3/8 x 1/2-inch) cylinders to exposures of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

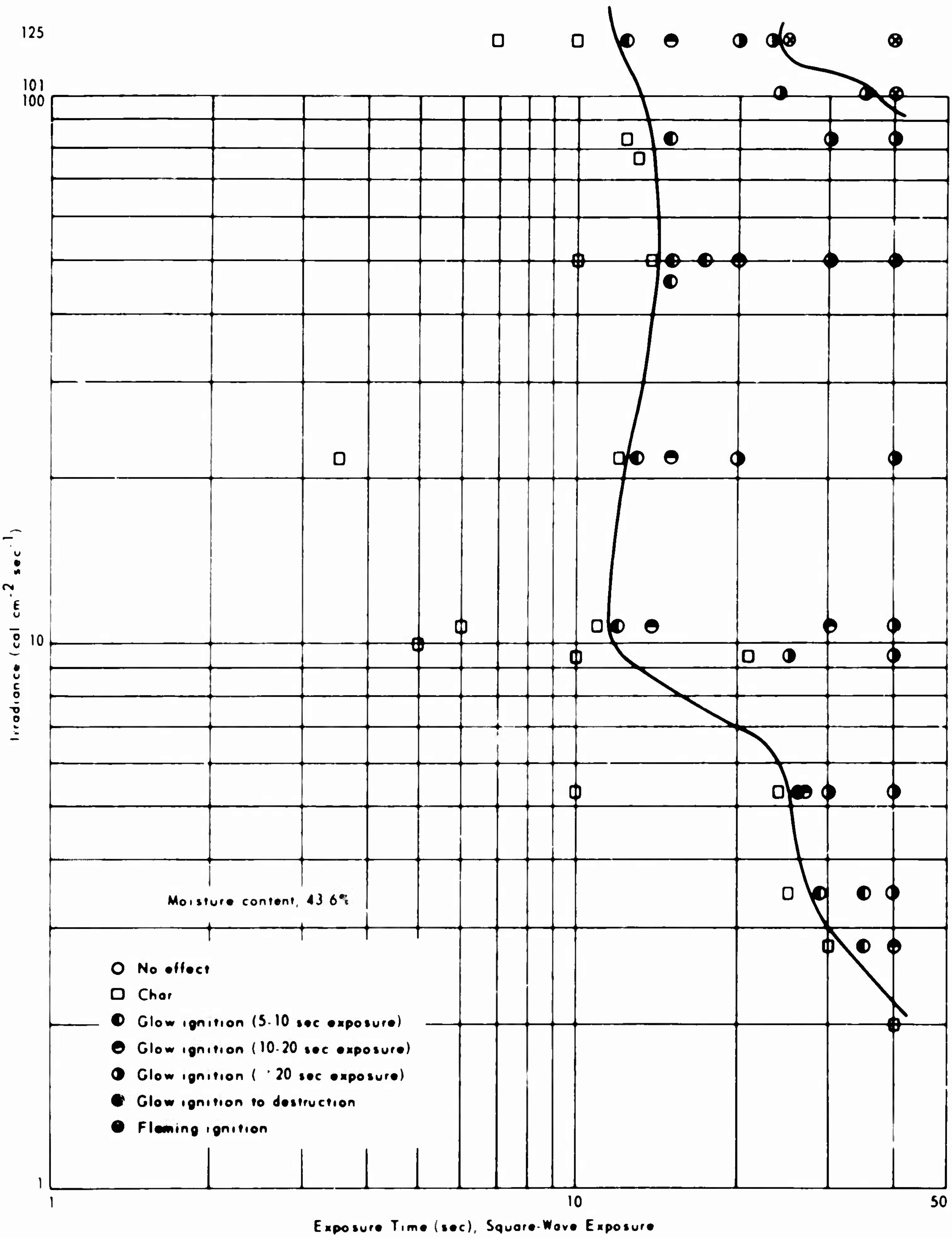

Figure 15. Response of maple (3/8 x 1/2-inch) cylinders to exposure of thermal radiation from a high-intensity carbon arc as a function of irradiation and exposure time.

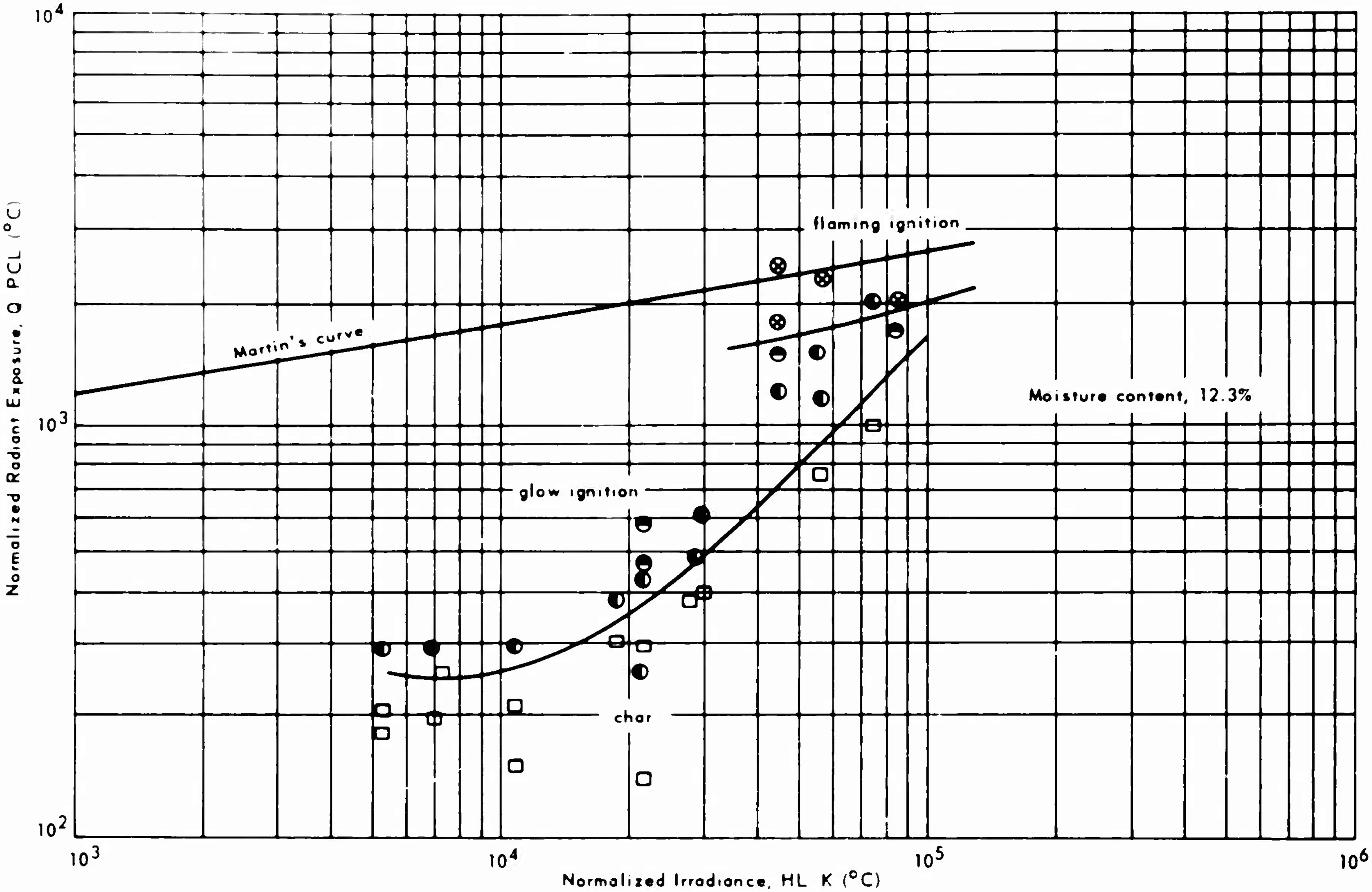

Figure 16. Ignition behavior of thick wood — ponderosa pine, 1/2-inch thick.

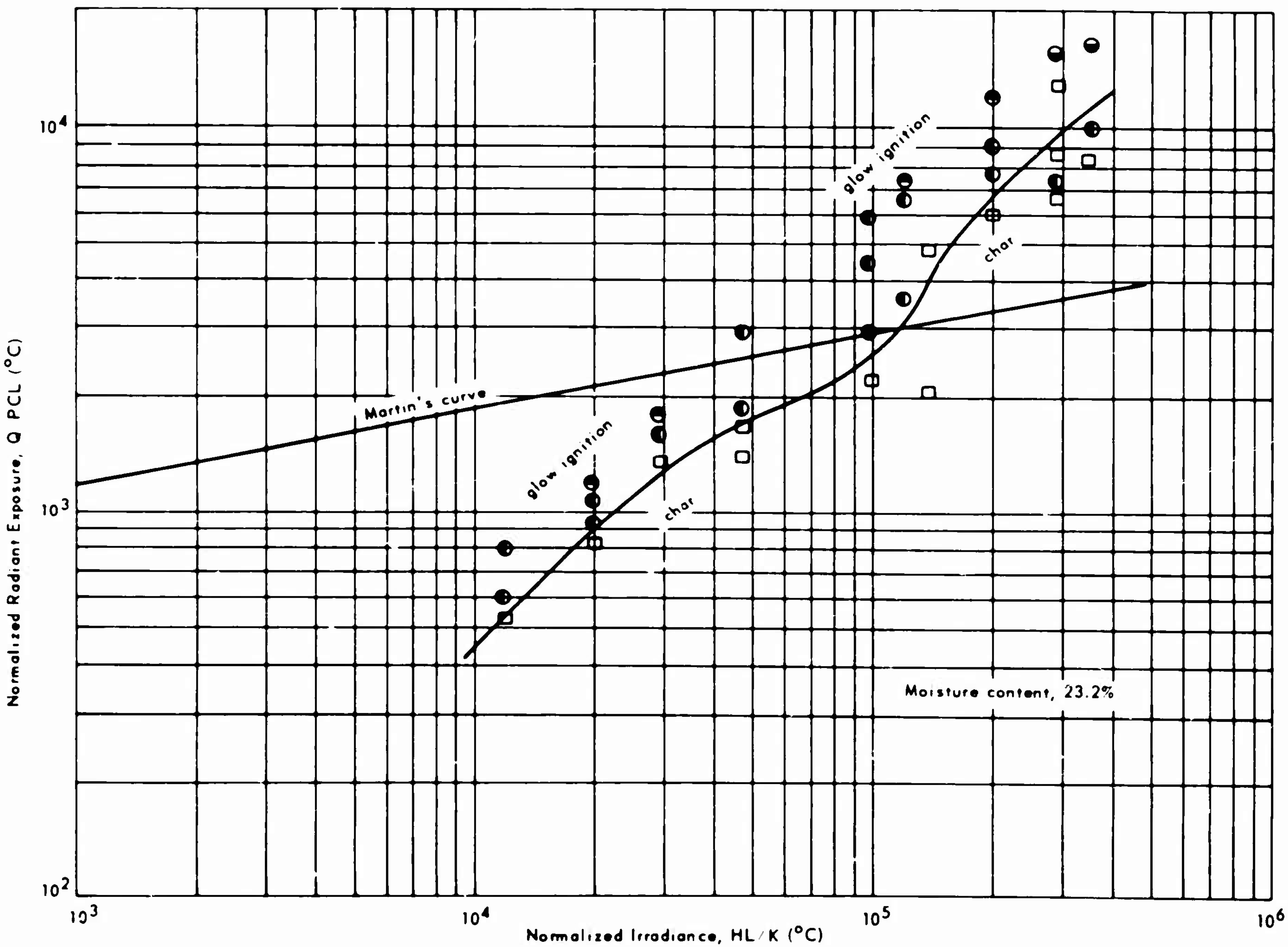

Figure 17. Ignition behavior of thick wood — Doublas fir, 1/2-inch thick.

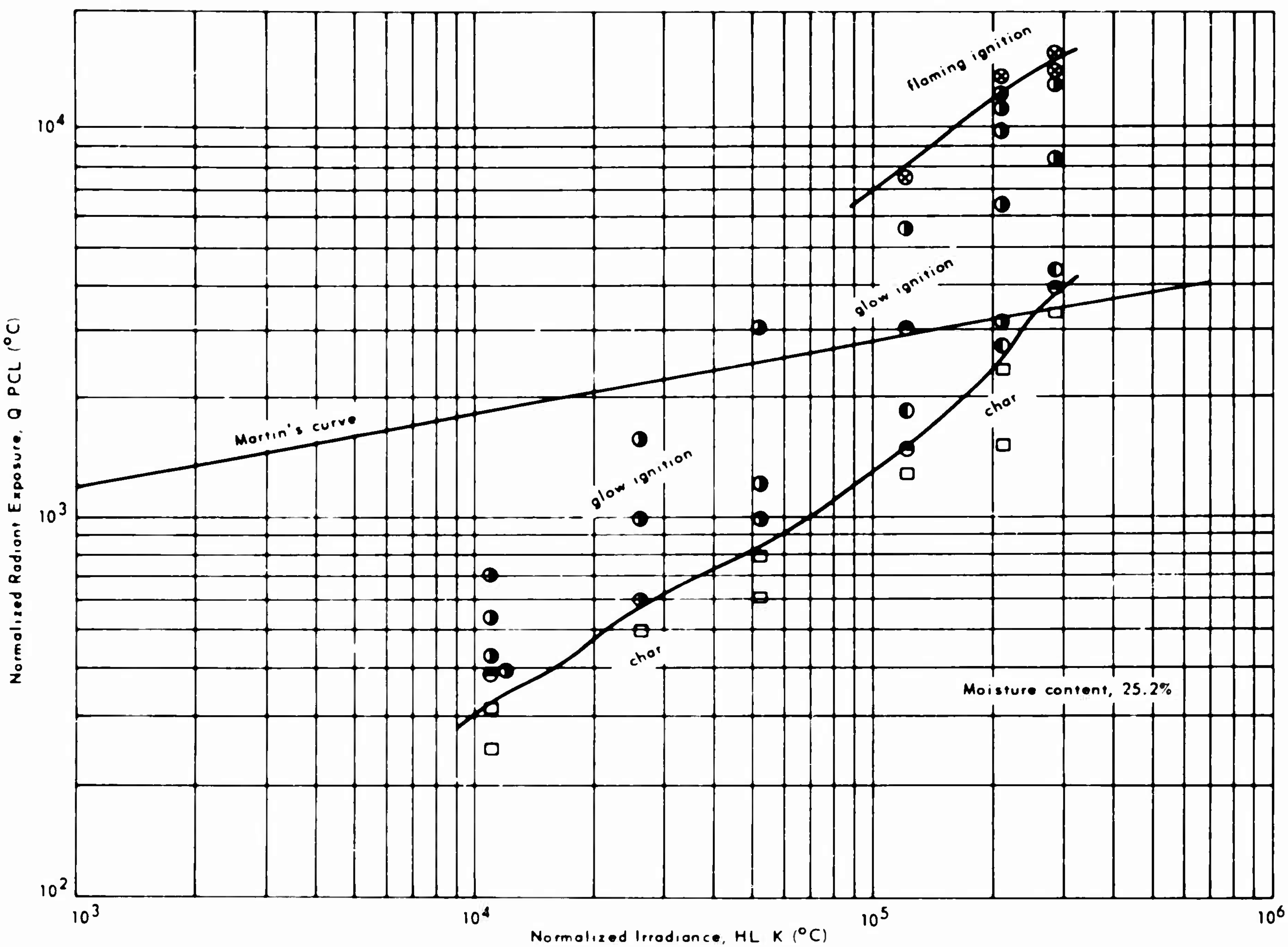

Figure 18. Ignition behavior of thick wood — maple, 1/2-inch thick.

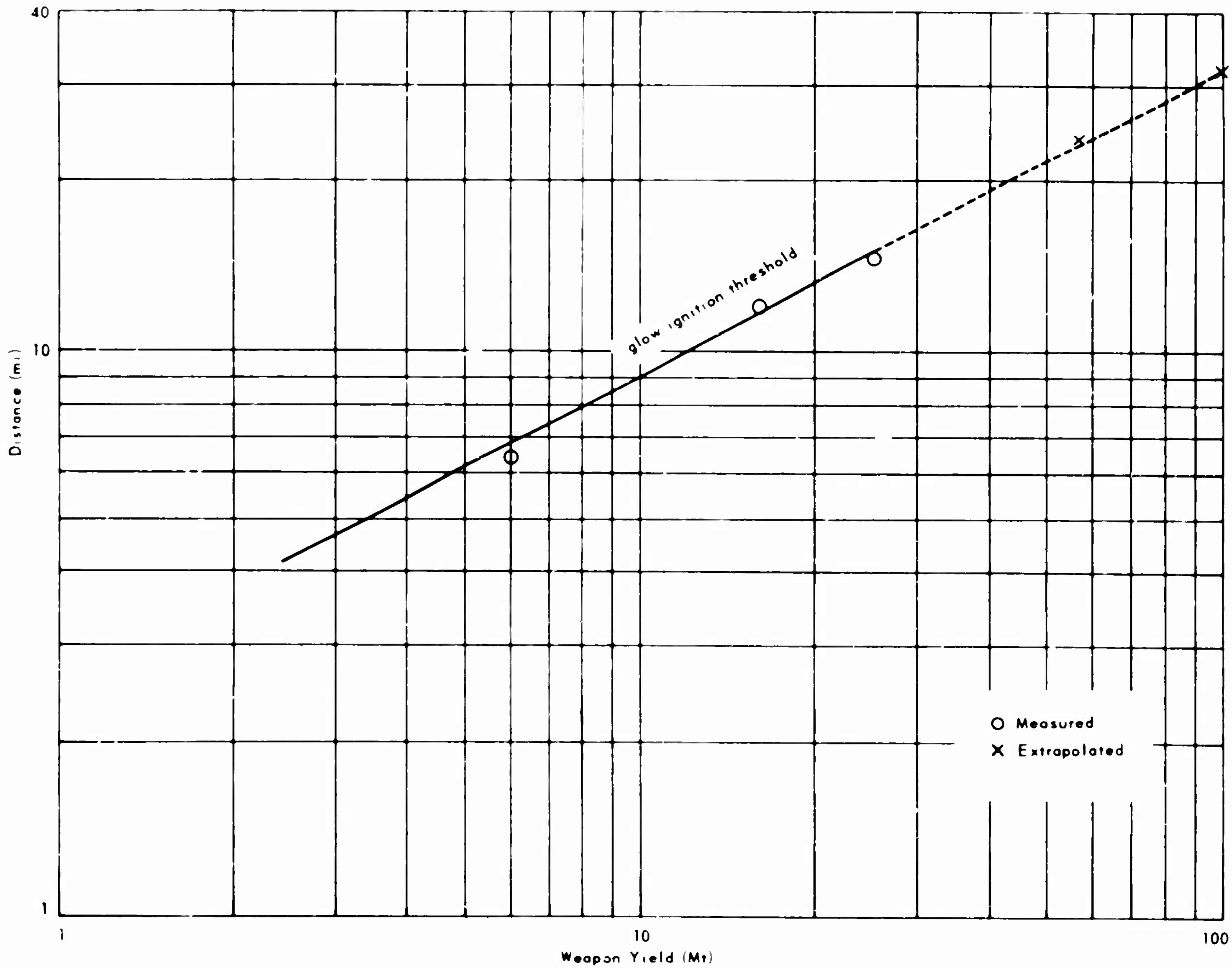

Figure 19. Distance for glow ignition as function of weapon-yield threshold value for ponderosa pine.

Appendix

HIGH-INTENSITY THERMAL-RADIATION FACILITY AT NCEL

INTRODUCTION

When a nuclear weapon is detonated in the atmosphere, it emits large quantities of thermal radiation in the optical region.[1,2,3,4] During this emission, the radiation corresponds to that of a black body of about 6,000 K (approximating the spectral distribution of solar energy received on earth).[4,5] In any study of the thermal-radiation effects of nuclear weapons, only the radiation in the spectral region from about 3,000 A[6,7,8] to 2.5 microns needs to be considered, since this region has about 95 percent of the total thermal energy emitted in a nuclear detonation.

The ultraviolet end of the spectrum is terminated by the absorption of the air, and significant amounts of energy are received only at wavelengths greater than 3,000 A.[6,7] Similarly, water vapor and carbon dioxide in the atmosphere absorb practically all of the infrared radiation at wavelengths greater than 2.5 microns.

High-intensity carbon arcs have practically the same spectral energy distribution as solar radiation or a nuclear weapon detonated in the atmosphere.[10,11] They have a very high intrinsic brightness and color temperature (6,000 K) and a relatively stable output of radiant energy as a function of time. Carbon-arc lamps have been found to be extremely well suited for laboratory experiments in thermal radiation. These arcs are readily available, having been used by the armed forces as light sources for searchlights, as well as for projection of motion pictures. They are being used, with various mirror arrangements, in laboratory experiments to simulate the thermal radiation delivered by nuclear weapons.

The effects produced by carbon-arc sources in the laboratory and the effects of thermal radiation from nuclear weapons in the field have shown good correlation.[12] In fact, there has been such good correlation that one can, with confidence, extrapolate laboratory exposures made with carbon arcs to exposures received from the detonation of a nuclear weapon. Consequently, the high-intensity thermal-radiation facility can be used for various tasks assigned to NCEL by BuDocks. A typical example is the determination of the glow-ignition limits of several types of thick wood samples.

EQUIPMENT

The thermal-radiation facility at NCEL uses an Army high-intensity carbon-arc lamp, modified by the Mole Richardson Company, with two paraboloidal 60-inch-diameter mirrors to concentrate the radiation.

The components for this equipment were obtained from the Naval Radiological Defense Laboratory in San Francisco and arranged (Figure 20) in a fashion similar to that described by Butler.[10,13]

This equipment was modified by incorporating an air-operated shutter with timing controls so that the system was essentially like that described by Day et al.[14] In the carbon-arc lamp, both the positive and negative carbon holders were replaced by water-cooled holders. The positive carbon holder is a pure silver, hollow, machined casting. Silver was used rather than copper, because silver oxide is a good electrical conductor, whereas copper oxide exhibits irregular electrical conductivity when used as a positive carbon holder. A water-cooled silver positive electrode gives a more uniform light output and permits operation of the lamp at much higher currents than an air-cooled copper positive electrode.

The thermal-radiation facility at NCEL is best shown by the following drawings and photographs.

Figure 20 indicates the general layout of the entire facility. Figure 21 shows the complete thermal-radiation system in operation. Figure 22(a) is an isometric view of a plane through the best focus of the collimating (collecting) mirror perpendicular to Z, the optic axis of the system. The spatial distribution of thermal energy near the focus of this mirror is shown in Figure 22(b), (c), and (d). The plane in Figure 22(a) has two directors, x and y, at right angles to each other and to Z. The intensity in arbitrary units (100 at the best focus) is plotted as a function of distance from the optic axis. These curves are very similar to those published by other authors. The only unusual feature is the rather large depth of focus in the Z direction. The intensity is almost constant for a distance of about 3/8 inch near the focus along the Z axis. This means if the 1/2-inch sample is placed at a point close to Z = 3/8 inch toward the mirror, as the sample burns back, the intensity will be relatively constant for almost its entire length.

Figure 23 is a view looking toward the arc and collimating mirror. It shows the various attenuating screens, not as they are normally used, but positioned to reveal all the screens. In normal use, one or more of the screens would be all the way down, intercepting the entire beam of radiation being reflected by the collimating mirror. These screens give measured attenuation steps from 0.8 to 0.025. If the aluminum attenuating plate shown in Figure 24 (C') is used, the attenuation can be increased to 0.0018. Various combinations of these screens will give almost any desired irradiation up to the maximum value. At the present time, this is about 80 cal/cm^2 sec. The mirrors are badly corroded and will be replaced with newly aluminized mirrors, now on hand, when higher values of irradiance are desired.

Figure 24 shows the concentrating mirror with the exposure table and the control console. In the background, the aluminum attenuating plate with holes can be seen. This plate is also useful for focusing and lining up the optical system.

Figure 25 shows the carbon-arc lamp with its water-cooling hoses and drive rods. The water-cooled silver positive head, H, holds the positive carbon in its normal operating position. The water-cooled negative carbon holder electrode, I, is in its normal operating position.

Figures 24 and 26 show views of the exposure platform, F, with the water-cooled beam-defining aperture, G, water-cooled dowser, P, and air-driven shutters, S_1 and S_2.

To make an exposure, the water-cooled dowser, which protects the shutter blades, moves to the right to the position shown in Figure 26. When it is at the end of its travel, a microswitch is closed, which opens shutter blade S_1. After a time pre-set by the control timer on the console, shutter blade S_2 is closed, and the dowser closes to protect the light aluminum shutter blades. The exposure time can be automatically controlled for exposures from 0.04 to about 10 seconds, and manually controlled for exposures as long as may be desired. The times are all measured on the electric clock timer, which reads to 1/100 second. This can be seen in Figure 23, as can the automatic timer for controlling the shutter.

Figure 27 shows the following: A sample, S, in its holder; the beam-defining aperture, G; and one of the shutter blades closed, with its driving crank mechanism.

OPERATION

The procedure for exposing a sample is as follows: First, an exposure intensity is selected, and an appropriate combination of screens is placed in the parallel beam from the carbon-arc source. An appropriate time is selected. A water-cooled calorimeter is placed at the exposure position of the beam-defining aperture. The intensity of the beam is measured at this focus. If it is not the desired intensity, the attenuating screens are changed until the desired intensity is achieved. The sample is placed in the exposure position. The exposure is made, the time recorded, and the effect on the sample observed. This procedure is followed in making thermal-radiation studies.

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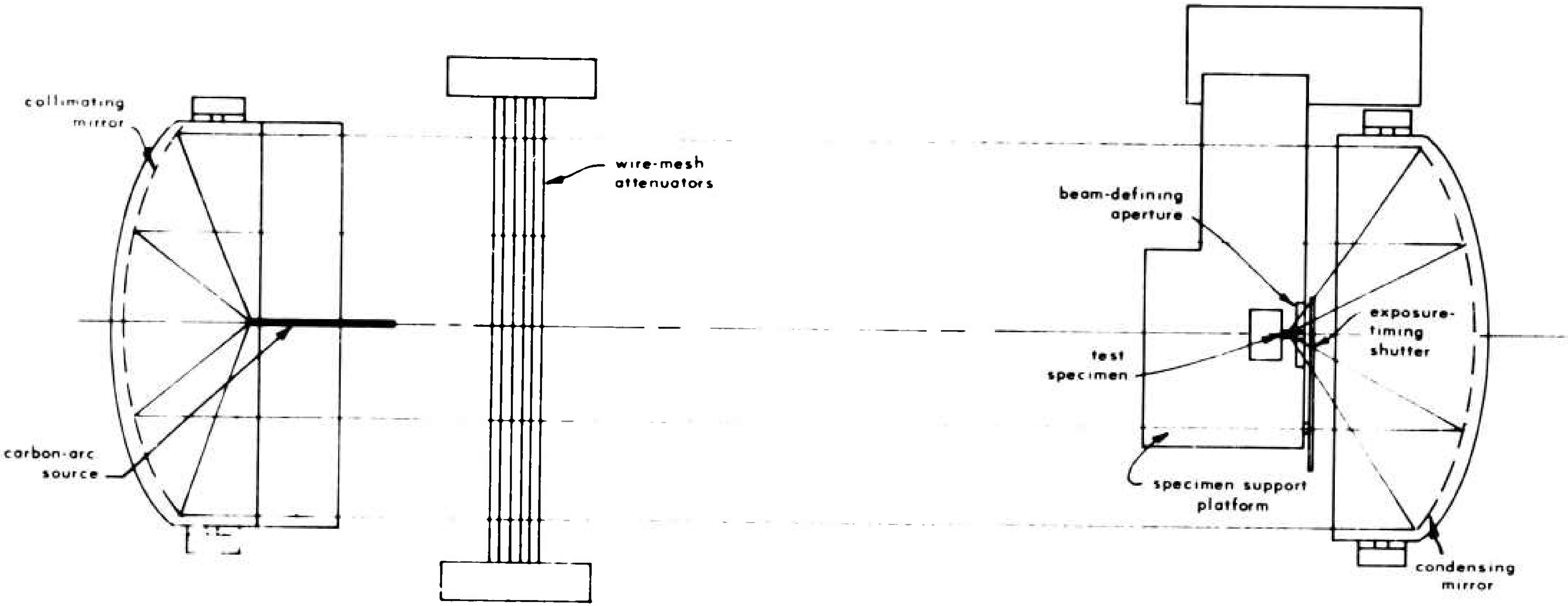

Figure 20. Plan view of thermal-radiation facility.

Figure 21. Complete thermal-radiation facility in operation.

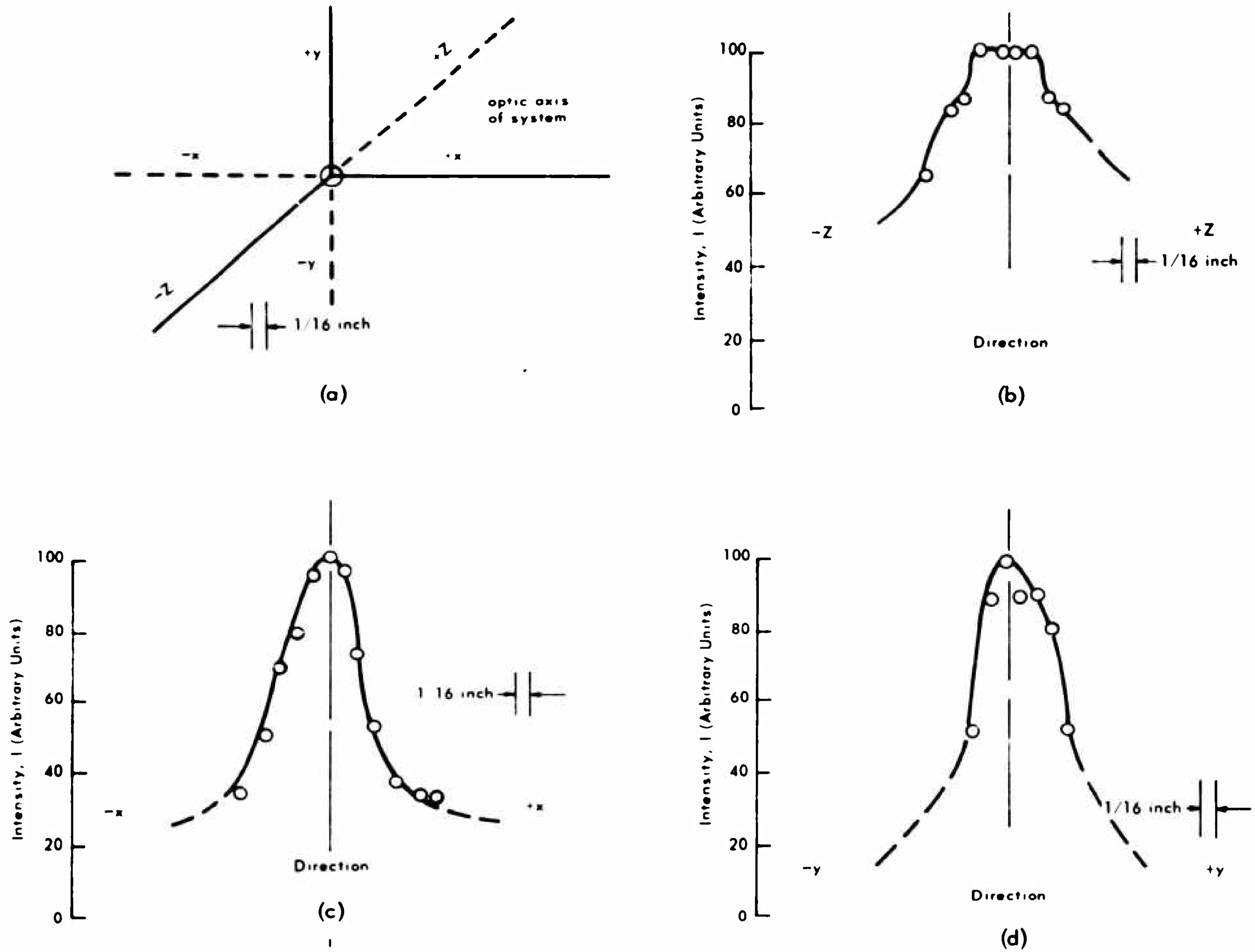

Figure 22. Plot of thermal energy received at various distances from the focal region.

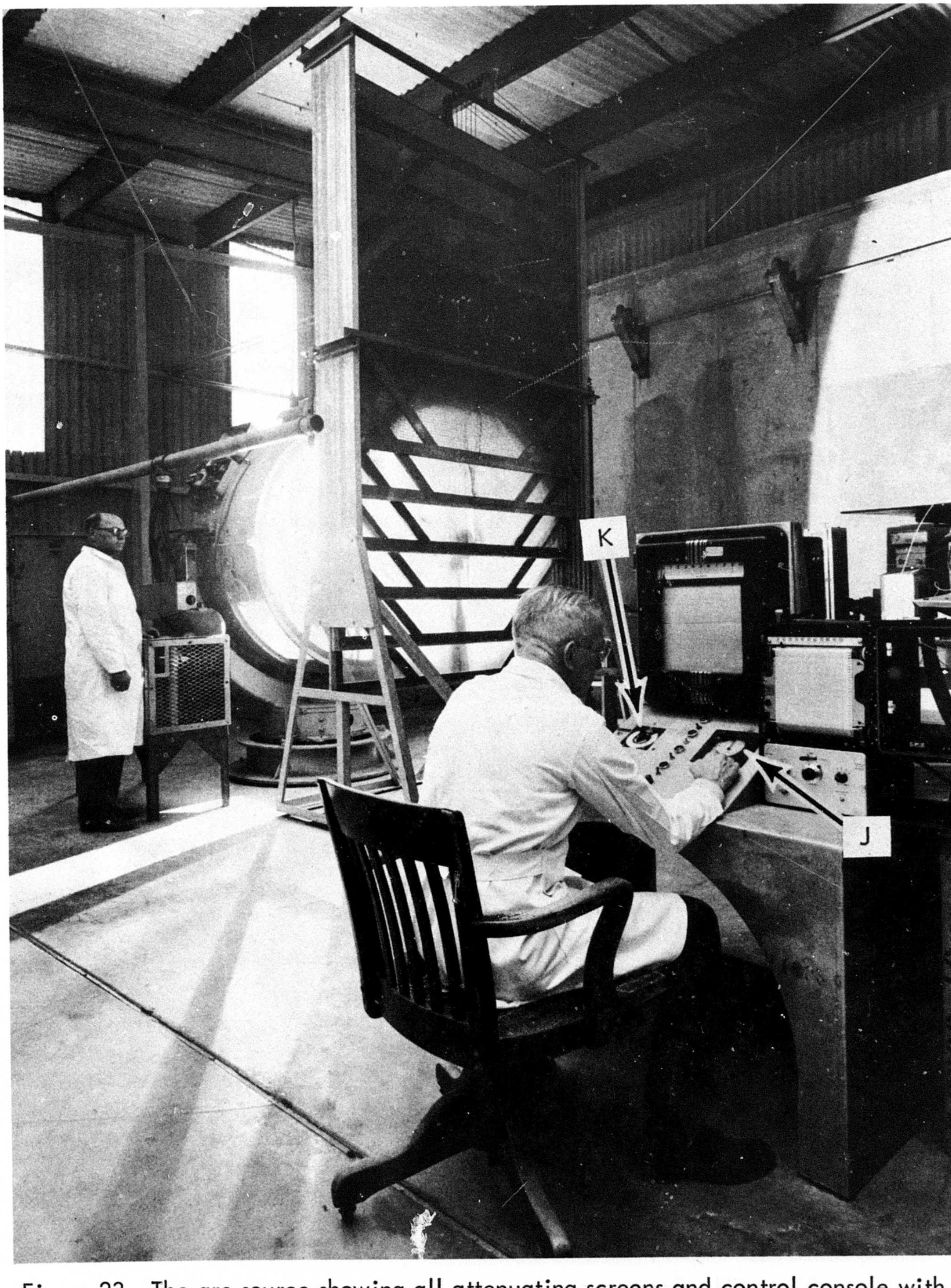

Figure 23. The arc source showing all attenuating screens and control console with timer, K, and clock, J.

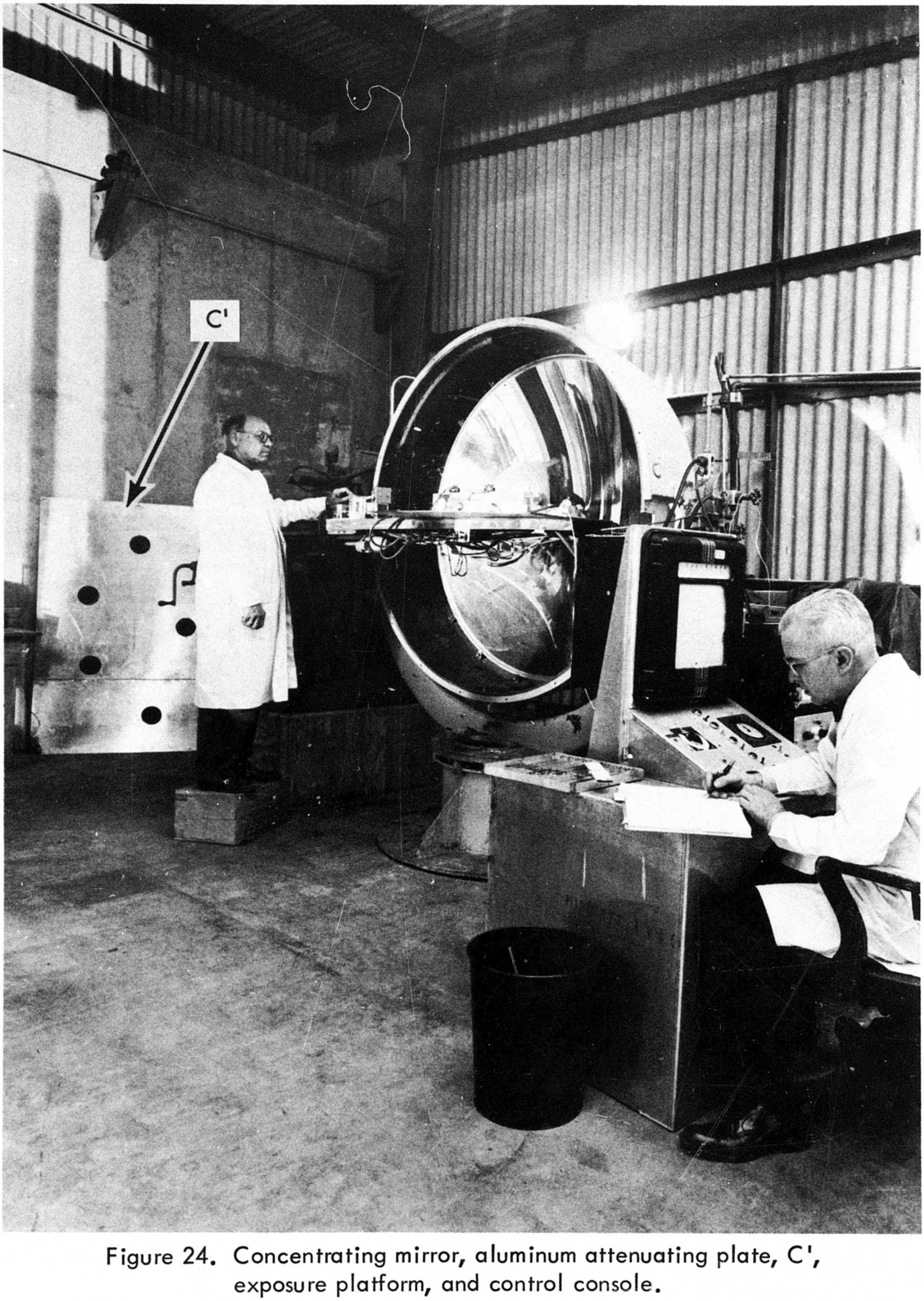

Figure 24. Concentrating mirror, aluminum attenuating plate, C', exposure platform, and control console.

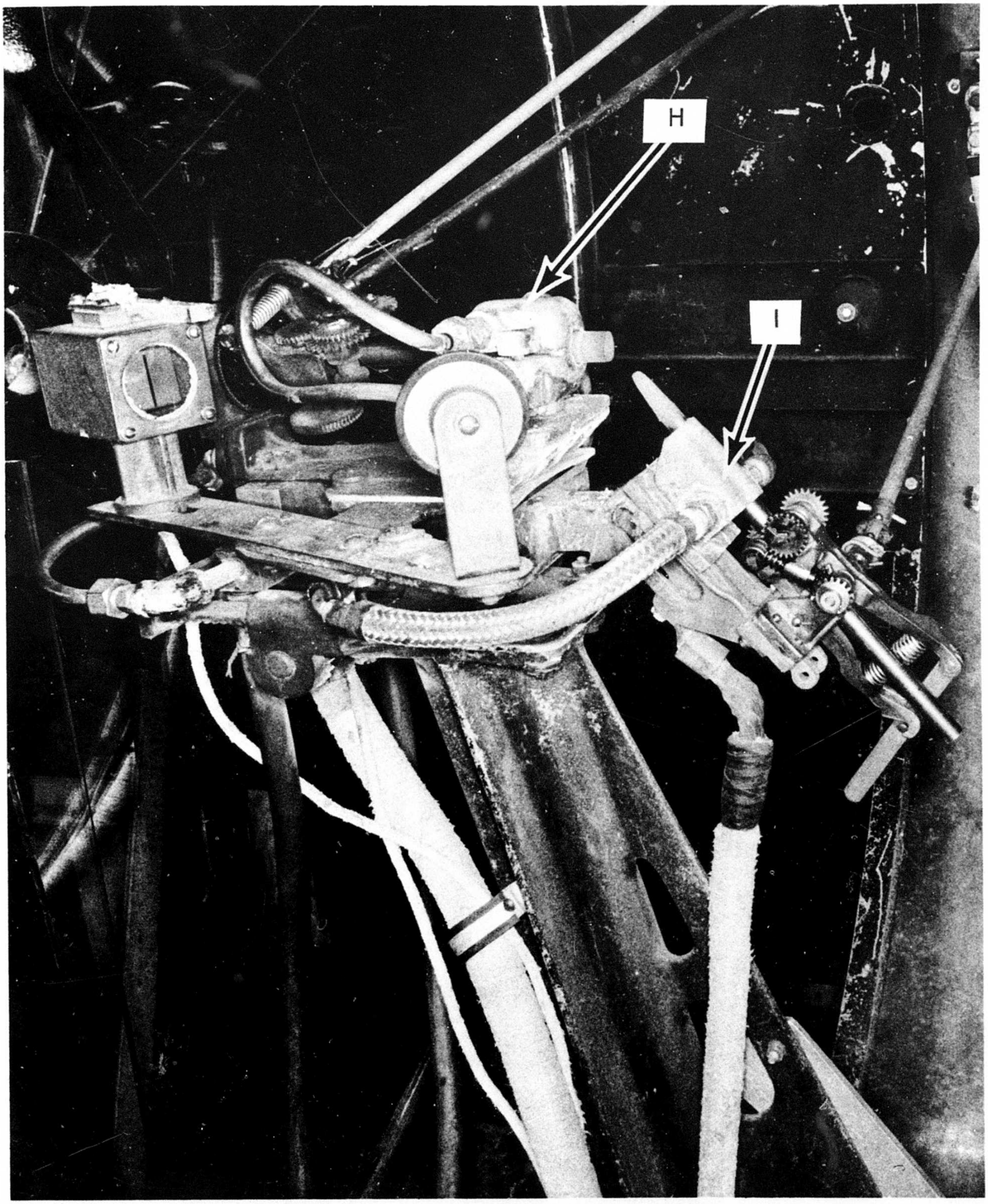

Figure 25. Arc lamp showing water-cooled positive carbon holder, H, and negative carbon holder, I, with power leads and positive-carbon-positioning system.

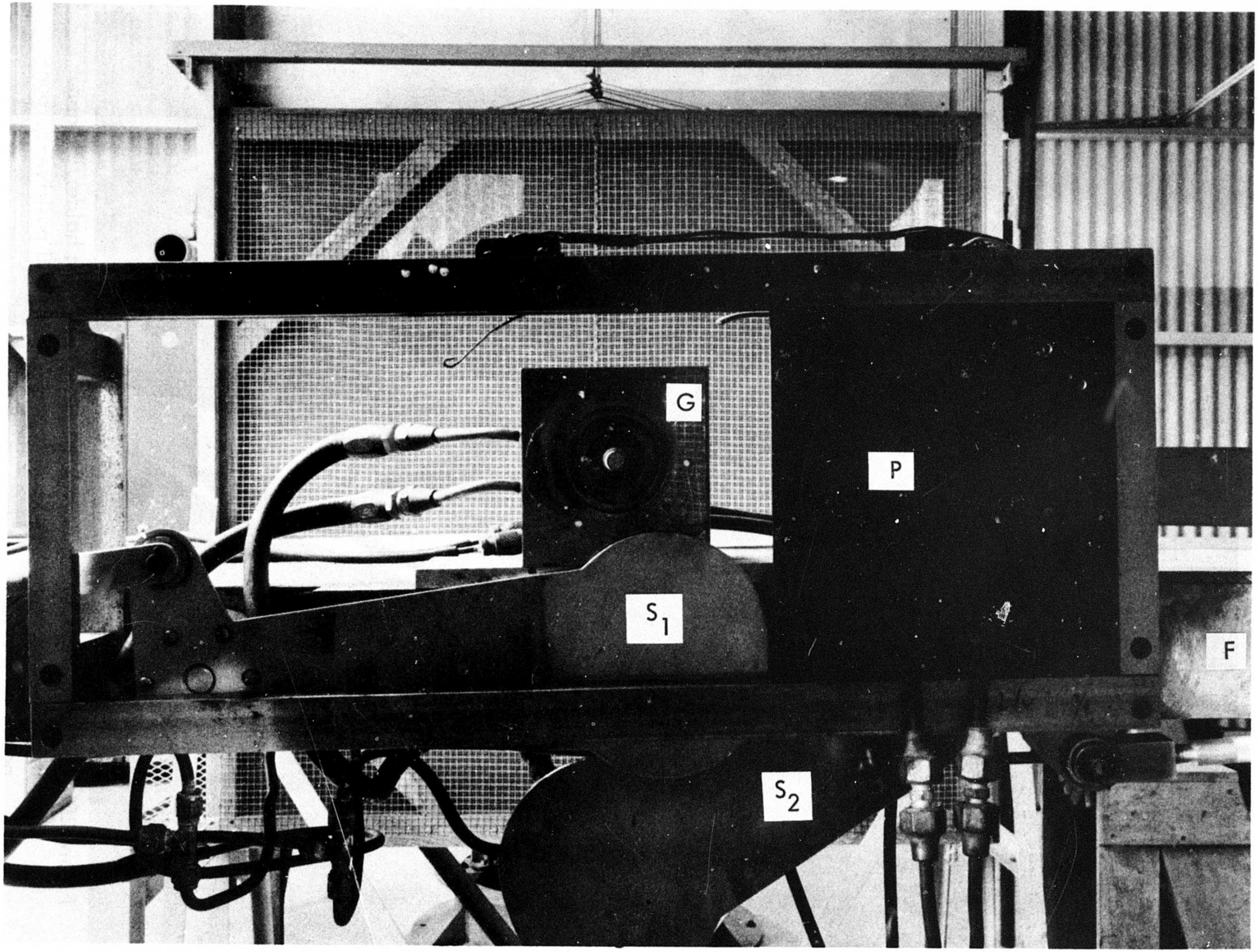

Figure 26. Rear view of exposure platform, F, shutters S_1 and S_2, water-cooled dowser, P, and water-cooled beam-defining aperture, G.

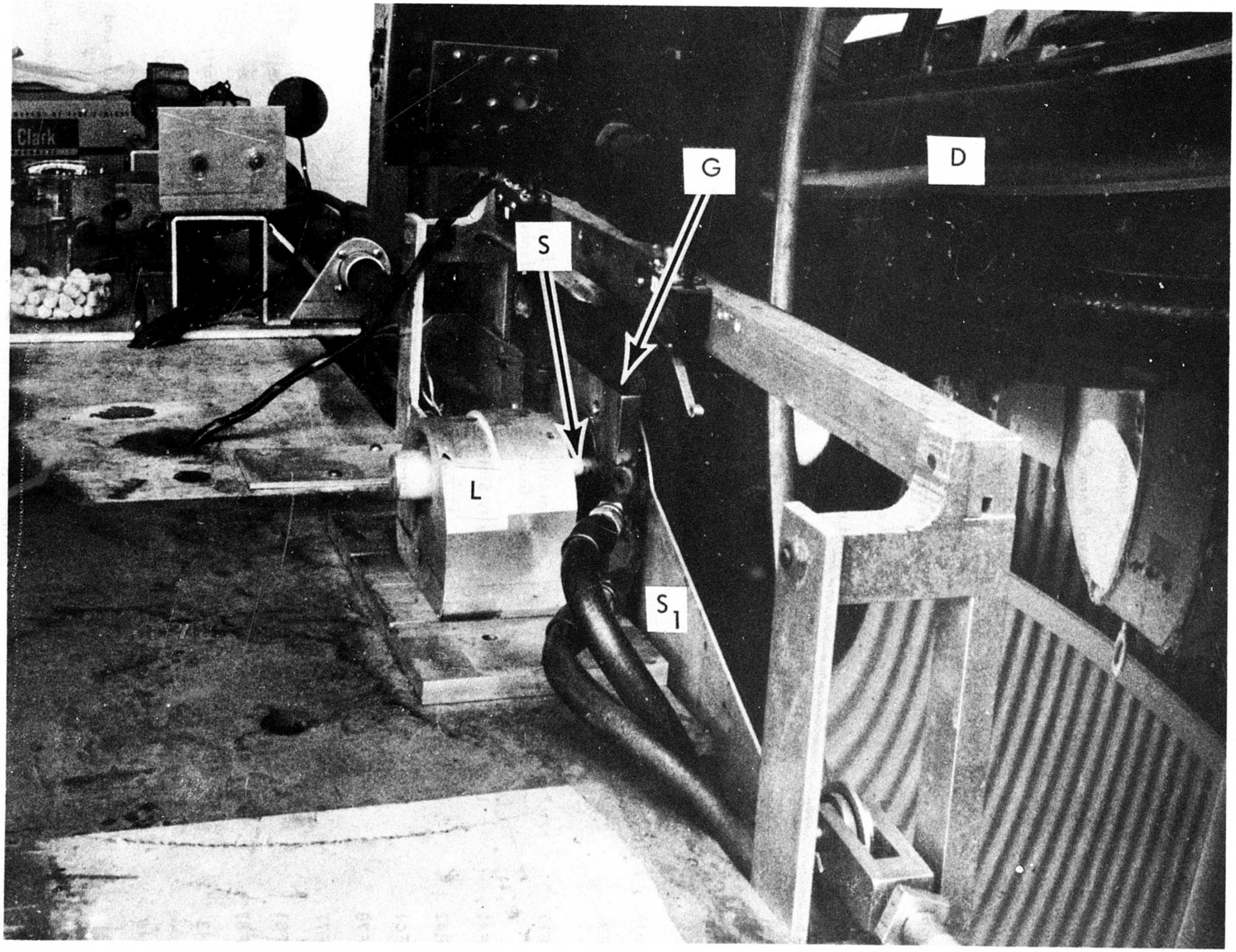

Figure 27. The exposure platform showing condensing mirror, D, one shutter blade, S_1, water-cooled beam-defining aperture, G, specimen holder, L, and specimen, S, in exposure position.

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13 ABSTRACT

An investigation was undertaken to determine the probability of ignition of thick woods by thermal radiation. A carbon-arc source was used to simulate the thermal radiation from a nuclear weapon.

Measurements were made to determine the irradiance and time necessary to produce glow and flaming ignition in ponderosa pine, Douglas fir, and maple. The results of this study are presented in the form of graphs of irradiance as a function of time for several moisture contents for each type of wood. In all cases on the graphs, the locations of the areas of char, persistent glowing ignition, and persistent flaming ignition are shown. The values of Q, total thermal energy necessary to produce sustained burning (with or without flame), can be easily computed from these data. They range from a minimum value of about 19 cal/cm^2 for very dry pine to several thousand calories/cm^2 for wood with a very high moisture content. It was concluded that for sound solid woods of a normal moisture content, it is almost impossible to start continued ignition with nuclear weapons of a size less than about 100 Mt at a distance where blast damage would not be severe. An appendix describes the high-intensity thermal-radiation facility used to conduct the investigation.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Wood						
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